ANGIOGRAPHIC VARIANTS OF COLLATERAL BLOOD FLOW AND THEIR SIGNIFICANCE IN CORONARY CHRONIC TOTAL OCCLUSION RECANALIZATION

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The aim of the investigation was to classify the variants of angiographic collateral blood flow in postocclusal segments of coronary arteries, and to determine the significance of each of them in achieving successful endovascular recanalization of coronary chronic total occlusion (CTO).

Materials and Methods. The study involved 128 patients (105 males and 23 females), with a mean age of 56.0±0.6 years. Between 2009 and 2011 the patients underwent endovascular intervention for CTO in the Specialized Cardiovascular Clinical Hospital, Nizhny Novgorod. Stable FC II–III angina (NYHA) had been diagnosed in all patients. The anterior descending artery was occluded in 39% of cases, the anterior coronary artery — in 41% of cases, and the circumflex artery — in 8% of cases, while, in all other cases, lateral branches were involved. The mean occlusion duration was 41.0±4.3 months (from 3 months to 20 years). The lengths of the occlusions ranged from 4 to 50 mm. According to the J-CTO scale, 47% cases had mild occlusions, 32% — moderately severe, and 21% — severe or very severe occlusions. All patients underwent CTO recanalization using endovascular antegrade techniques.

Results. Based on the findings of selective coronography of the CTO patients we distinguished angiographic variants showing different types of collateral blood flow in the postocclusal segments of the coronary arteries, and established a significant dependence of the success of recanalization on the type of collateral blood flow seen in the postocclusal segments. For example: where the type of blood flow can be classified as RAI-III or RAI-Ia, an intervention is more frequently successful than with the other types. In antegrade mechanical recanalization, it is collateral blood flow of type RAI-Ib which results in fewer positive results.

Conclusion. The RAI classification which we have established can be recommended as an option for the systematization of angiographic manifestations of collateral blood. This is of great practical importance, since it enables assessment of the extent of a lesion and the selection of an interventional correction technique.

Key words: coronary chronic total occlusion; CTO recanalization; collateral blood flow; bilateral contrast; retrograde contrast.

Atherosclerotic lesions of coronary arteries are the main morphological substrates, which determining the development of ischemic heart disease as one of the leading causes of death, globally [1]. The gold standard for the diagnosis of an atherosclerotic lesion of the coronary arteries is still selective coronary angiography (SCAG) [2]. With the development of endovascular technology, minimally invasive treatment of the hemodynamic manifestation of atherosclerosis with an optimal clinical outcome has become possible. The last decade has seen the development of a great number of tools and techniques which can perform interventions for coronary arteries having extensive atherosclerosis [3–5].

Coronary chronic total occlusion (CTO) are traditionally considered the lesions that are hardest for interventional correction [6]. Such atherosclerotic lesions of the coronary artery, with complete blockage of the lumen for more than 3 months, result in the formation of collateral blood flow distal from the lesion [3].

On the basis of SCAG, the frequency of occurrence of CTO is 20–30% [7].

CTO recanalization is a physiologically justified operation, as it provides adequate blood supply to the required area of the myocardium, enhances its contractive ability and the electrical activity of the heart, positively affecting its remodeling [4, 8]. However the endovascular correction of these occlusions is associated with a high risk of intraoperational complications [9]. The effectiveness and safety of intervention depend on many factors and are determined by the quality of visualization of the artery of interest [10].

The complexity of an upcoming recanalization of CTO can be identified on the J-CTO scale, where the type of stump, presence of calcinosis, tortuosity in the area of

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occlusion, length of lesion, and any former interventions are taken into account. CTOs scoring 5 on the J-CTO scale have the greatest complexity [11].

The required level of visualization of postocclusal segments at the stage of diagnosis, and during therapy, is provided by the collateral blood flow. The degree of development of the collaterals, as well as the methods used for contrasting the coronary arteries, show the quality of filling of the artery segments located more distally from the occlusion. In the region where there is extensive collateral blood flow one can observe postocclusal segments along the entire length of the lesion, and measure the length and number of floors. This information makes it possible to plan how to correct the lesion, making the intervention more effective and safer [12–14]. Lack of visualization of artery segments more distal from the occlusion increases the risk of inserting the coronary conductor outside the lumen of the vessel, which can cause mechanical perforation of the artery and the possible development of cardiac tamponade [14].

The notion of a collateral blood flow is, to a great extent, synonymous with the notion of retrograde blood flow, as the filling of the postocclusal segments is performed in opposition to the antegrade one. Collateral coronary blood flow can be subdivided as intra- and inter-system, depending on the donor of the collaterals [15].

In the case that the contrasting of the target artery through the intra-system collaterals is less than optimal, it is possible to use the method of counter-lateral and bilateral injection of the contrast medium into the coronary pool, to enhance the quality of visualization as a result of the use of the inter-system collaterals [5, 14].

At present there are no publications available which provide classifications of the collateral blood flow to determine the type of angiographic visualization of the postocclusal segments of the artery. The existing, Retrop and Cohen classification, systemizes the variants of the development of the collaterals themselves, but it does not summarize any information about the filling of the recipient artery [16]. Such information about antegrade blood flow in the case of thrombosis of the artery is provided by the TIMI scale, but its descriptive features cannot be extrapolated to the postocclusal segments of chronically occluded arteries, due to the lack of information about the collateral blood flow and other defining substrates [17].

B. Meier's classification (1989) of collateral blood flow is closely descriptive, but it lacks systematization options for contrasting the postocclusal segments with respect to the distal capsule, although this information would be of great practical value for endovascular CTO recanalization.

Given the need for a classification to be used in diagnosis and during treatment, we decided to offer our version of systematization of the angiographic manifestations of collateral blood flow.

The aim of the investigation was to classify angiographic collateral blood flow types in the postocclusal segments of coronary arteries, and to determine the significance of each, in respect of the likelihood of achieving success in the endovascular recanalization of coronary chronic total occlusion.

Materials and Methods. The study involved 128 patients (105 males and 23 females) who underwent CTO endovascular intervention in the Specialized Cardio-surgical Clinical Hospital of Nizhny Novgorod from 2009 to 2011. The age of the patients was 56.0±0.6. All of them were diagnosed with stable angina of functional class II–III (NYHA). 33 patients (25%) had non Q-myocardial infarction, 70 (55%) had cicatrices on the myocardium, while in 25 (20%), in their anamnesis, and, according to the results of non-invasive investigation, no irreversible changes to the myocardium had been observed. Among the concomitant diseases: in 15 cases (12%), there was diabetes mellitus and in 111 cases (87%) — arterial hypertension. The initial ejection fraction of the left ventricle was, on average 54.8±0.7%. In 48 cases (38%) there was a disorder in segmental contractility of the heart: in 31 cases (24%) — hyperkinesia, in 15 cases (12%) — akinesia, and in 2 cases (2%) — dyskinesia. At SCAG, 87 patients (68%) had multiple lesions of the coronary arteries, and 41 patients (32%) had single-vessel lesions. In 39% of cases, the involvement was the anterior descending artery (ADA), in 41% of cases — the right coronary artery (RCA), and in 8% — the circumflex artery, while the remaining cases included a diagonal branch, the obtuse marginal branch, the posterior descending artery and the posterior lateral branch. The average duration of occlusion was 41.0±4.3 months (from 3 months to 20 years), with the length of the occlusion ranging from 4 to 50 mm.

The study was performed in accordance with the Helsinki Declaration (adopted in June 1964 (Helsinki, Finland) and reviewed in October 2000 (Edinburgh, Scotland) and approved by the Ethical Committee of the Nizhny Novgorod State Medical Academy. Each patient gave informed consent.

All patients underwent endovascular intervention for CTO recanalization. The complexity of the lesion was assessed according to the J-CTO scale. In 47% of cases these were mild occlusions, 32% demonstrated medium complexity, and in 21% — complex or very complex occlusions were present.

The interventions were performed in an X-ray operating theater equipped with a Siemens Axiom Artis (Siemens, Germany) digital angiographic device. Access was performed using the Seldinger method under local anesthesia through a femoral artery on one side. The patients underwent partial heparinization. The following guide catheters were used: JL, EBU, JR, JR SH or AR depending on the target artery. Variants of the antegrade CTO recanalization technique were applied in all patients.

Intervention commenced with the use of a hydrophilic conductor, this being substituted with a more rigid one if there was no positive outcome. On introducing the coronary conductor into the area of occlusion its extra- or intra-luminal location was determined on the basis of direct angiographic symptoms. In the absence of optimal visualization of the postocclusal segments, catheterization of the counter-lateral coronary artery was performed through the intra-system collaterals. For this purpose the access was performed with the Seldinger method through the "free" from the guide catheter common femoral artery. Then bilateral contrasting was performed to confirm, reliably, the position of the conductor outside or inside the lumen of the occluded vessel. The registration of the image was performed in several dimensions in order to provide optimal visualization of the target artery. Reliable intra-lumenal location of the conductor in the postocclusal segments of the required artery was considered to be confirmed by angiographic evidence in at least two dimensions. In some cases rotation angiography was used to clarify the conductor location.

At the next stage, balloon angioplasty of the damaged segment was performed, with further angiographic evaluation of the results obtained. Where there was restoration of the antegrade blood flow in the target artery the patient underwent complete heparinization. If there were indications stents were implanted to achieve the optimal angiographic result.

The intervention was considered successful if antegrade blood flow TIMI III occurred in the target artery, and there were no threatening dissections, thrombosis or compromised blood flow in the branches of the target artery. The results of angiography in DICOM (Digital Imaging and Communication in Medicine) format were analyzed with Syngo Fast View software.

The resulting data were processed with the use of a Microsoft Excel 2010 "analysis package". The correlation of the parameters was studied using the Spearmen nonparametric method of correlation analysis. The differences were considered statistically relevant at $p<0.05$ according to the Student's t-test.

Results and Discussion. After the analysis of the initial SCAG data of each patient, optimal variants of the retrograde contrasting of the postocclusal segments were selected. Their distribution according to the types of collateral blood flow was performed on the basis of two parameters: a) according to the quality of filling of the target artery more distal from the lesion due to intra- and inter-system collaterals, and b) according to the relative extent of collateral blood flow to the segment of the artery attached to the distal capsule of the substrate. To define the notion of retrograde contrasting of arteries the term RAI (retrograde artery imaging) was proposed with its values being scored from 0 to III, to characterize the enhancement of the quality of the postocclusal segments. Type RAI-I of blood flow was considered to be divided into two variants — RAI-Ia and RAI-Ib — depending on the presence or absence of visualization of the artery segment attached to the substrate (Fig. 1, 2):

RAI-0 — lack of visualization of the "recipient's" artery (Fig. 2, *a*);

RAI-Ia — filling of the artery fragments including those attached to the distal capsule of the occlusal substrate (Fig. 2, *b*);

RAI-Ib — fragmentary filling of postocclusal segments of the artery without visualization of the segment attached to the distal capsule (Fig. 2, *c*);

RAI-II — postocclusal segments can be traced over a significant length but without visualization of the segment attached to the distal capsule (Fig. 2, *d*);

RAI-III — tight collateral filling of the postocclusal segments of the artery from the distal capsule to the terminal branches (Fig. 2, *e*).

The distribution of these variants of collateral blood flow in the group of patients under study was performed in the following way (Fig. 3).

Analysis of the dependency of the success of recanalization on the type of collateral blood flow in the postocclusal segments let us identify their close correlation: with blood flow of types RAI-III and RAI-Ia, success was achieved more frequently than in the other cases. The presence of collateral blood flow of types RAI-II, and RAI-Ib to a lesser extent, led to positive results for antegrade mechanical recanalization (Fig. 4).

For the RAI-0 and RAI-Ib types of collateral blood flow, a relatively larger number of intraoperational complications were registered, together with the need for a longer period of fluoroscopy and a greater number

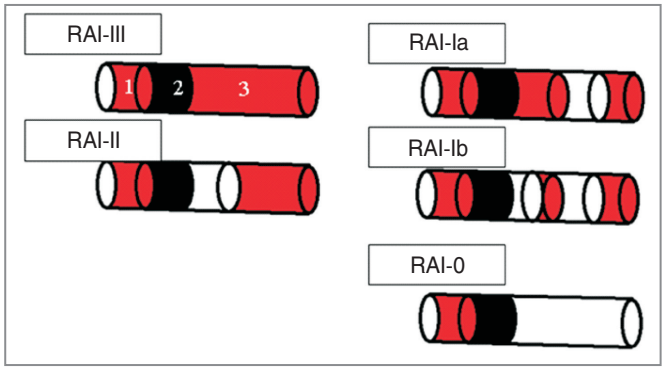

Fig. 1. Classification of the angiographic variants of collateral filling of the postocclusal segments of the arteries (RAI): *1* — segment of the artery more proximal to the occlusal substrate; *2* — occlusal substrate; *3* — segments of the artery more distal from the occlusal substrate. The color marks partial or complete contrasting of the artery

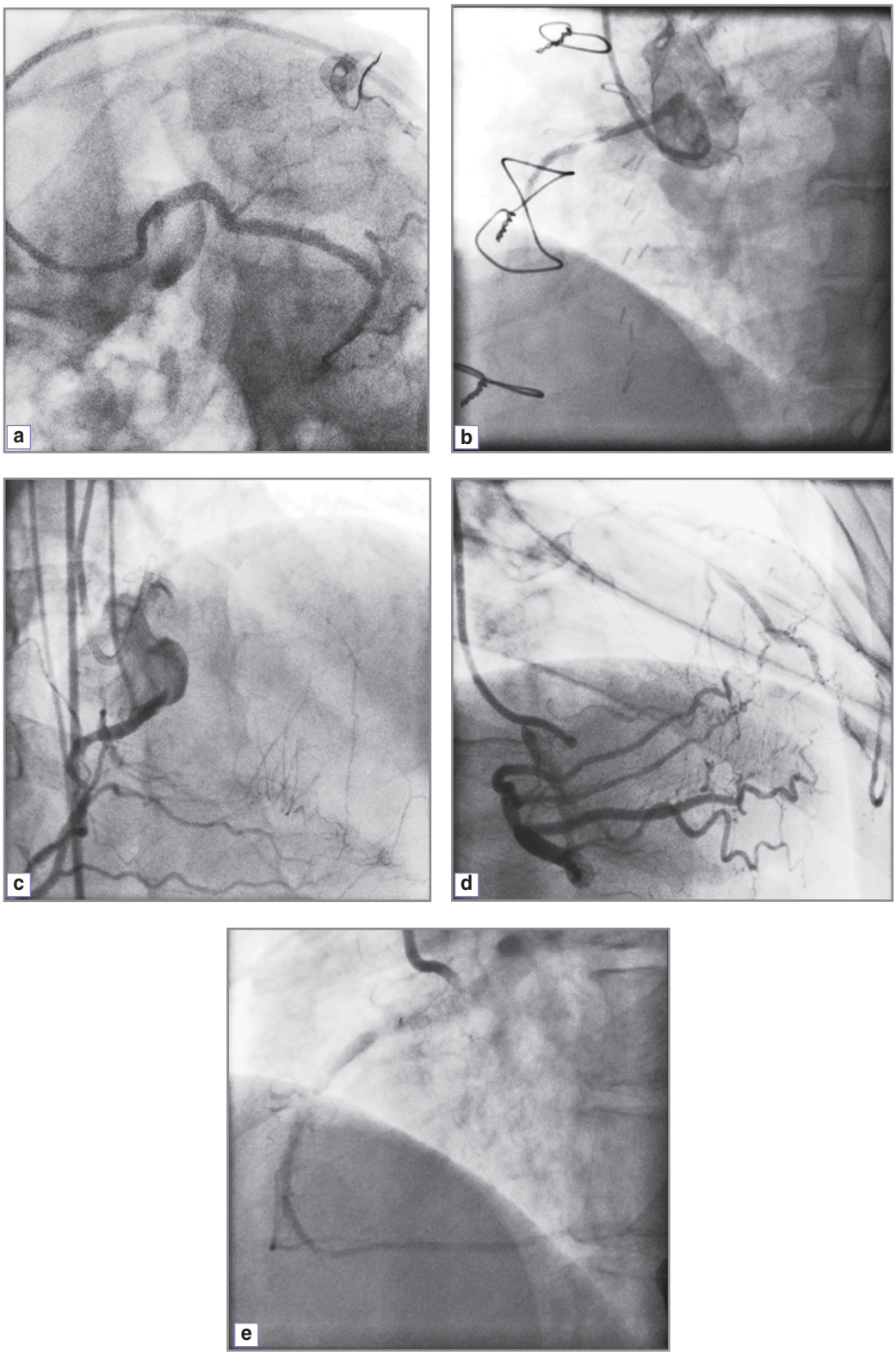

Fig. 2. Angiograms with the types of collateral blood flow according to the RAI classification: *a* — chronic occlusion of the anterior descending artery from the mouth, with a RAI-0 type of collateral blood flow; *b* — chronic occlusion of the proximal segment of the right coronary artery, with RAI-Ia type of collateral blood flow; *c* — chronic occlusion of the proximal segment of the anterior descending artery, showing the use of bilateral contrasting, here the type of collateral blood flow is RAI-Ib; *d* — chronic occlusion of the proximal segment of the anterior descending artery, with the use of bilateral contrasting, illustrating the RAI-II type of collateral blood flow; *e* — chronic occlusion of the proximal segment of the anterior descending artery, with RAI-III-type collateral blood flow

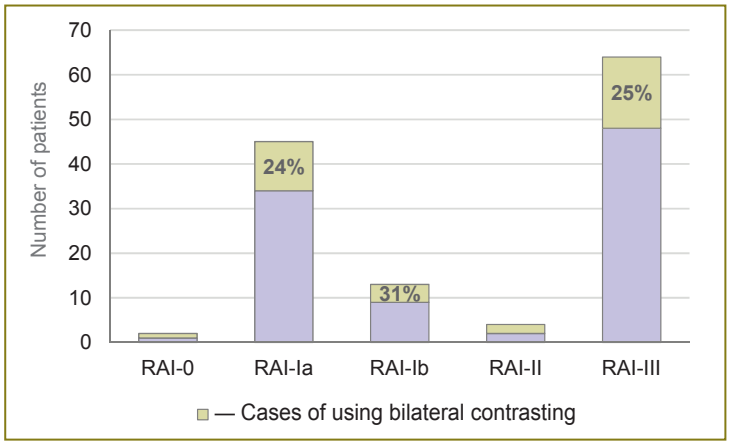

Fig. 3. Distribution of angiographic RAI types of collateral blood flow of patients with chronic occlusions of coronary arteries

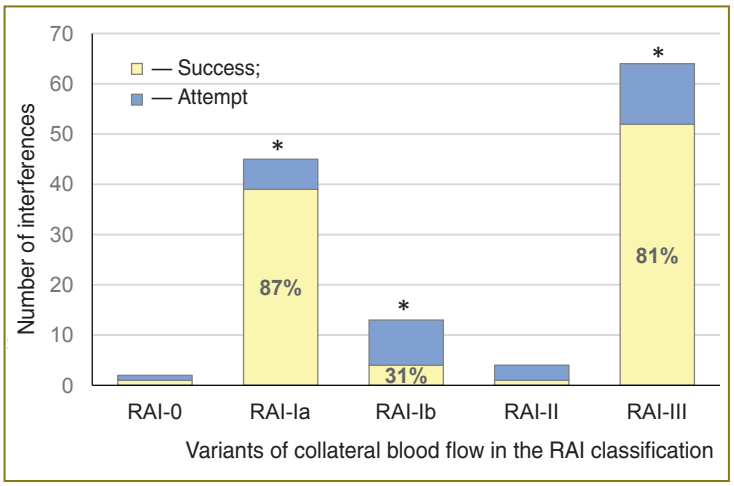

Fig. 4. Correlation between the success of recanalization and the type of collateral duct; * — p<0.005

of stents being required for achieving an optimal result (Table 1, 2).

Successful recanalization was performed in 97 cases (76%). The use of bilateral contrasting was required for 34 patients (27%) due to the lack of optimal contrasting of the postocclusal segments of the artery through the intra-system collaterals.

The intervention had to be terminated without a positive result in 31 cases (24%) due to a high risk of perforation of the artery, and to avoid exceeding the admissible amount of the contrasting substance being used, or the dosage of ionizing radiation.

In 13 cases there were intraoperational complications. During recanalization, 6 patients had longitudinal dissection of the left main coronary artery, with compromising blood flow more distally from the location of intervention, which required the implantation of additional stents. In two cases there was perforation of the target artery, which was eliminated with traditional methods. It should be noted that there were two cardiac tamponades that required additional puncture and drainage of the pericardium. There was complication of the access in the form of false aneurism which required extra surgical intervention. Among the complications registered were two intraoperational myocardium infarctions, one of which caused an uncontrollable fall of hemodynamics and the death of the patient during the operation.

Bu using appropriate methods for the optimization of visualization of postocclusal segments, for example, bilateral contrasting, one can prevent perforation of the artery leading to the development of cardiac tamponade, however its use increases the risk of access complications, and there is also the presence of an extra catheter at partial heparinization which can lead to a raised risk of thromboembolism of the coronary mouth. All other complications are nonspecific and do not depend on the chosen technique of contrasting of the coronary pool.

The optimal result achieved in 97 cases required on average 21.0±1.4 min of fluoroscopy, 341.0±11.5 ml of contrasting substance and the implantation 1.7±0.1 stents per patient, which corresponds to a good level of endovascular CTO treatment.

Thus, the RAI-Ia and RAI-III types of collateral blood

Table 1

Success-rates for the recanalization of chronic occlusions of collateral blood flow depending on the type of retrograde contrasting (variant of the collateral blood flow)

RAI type	Fluoroscopy time, min	Number of stents	Complications
RAI-0 (n=1)	56.00±0.0	3.0	1
RAI-Ia (n=39)	20.74±2.07	1.8±0.2	3
RAI-Ib (n=4)	46.25±9.96	2.8±0.6	1
RAI-II (n=1)	41.00±0.0	4.0	0
RAI-III (n=52)	18.44±1.58	1.7±0.1	4

Table 2

Attempts at recanalization of chronic occlusions of collateral blood flow depending on the type of retrograde contrasting (variant of collateral blood flow)

RAI type	Fluoroscopy time, min	Complications
RAI-0 (n=1)	22.00	1
RAI-Ia (n=6)	26.17±4.96	1
RAI-Ib (n=9)	23.89±3.87	1
RAI-II (n=3)	49.67±13.27	0
RAI-III (n=12)	35.33±4.04	1

flow are optimal during CTO recanalization, as they enable confirmation of the intra-luminal location of the coronary conductor and perform safely during catheter balloon angioplasty and further stenting of the required segment of the artery. Identification of the real length of the occlusion is even possible with collateral blood flow of types RAI-Ia and RAI-III, and this is important for planning the correction of the lesion and assessing the quantity of drug-coated stents requiring implantation in the case that there is longitudinal dissection of the target artery.

Where there is retrograde blood flow of types RAI-0, RAI-Ib or RAI-II, due to intra-system collaterals, the quality of visualization of the postocclusal segments of the target artery can be optimized by the use of bilateral contrasting.

With aggressive CTO recanalization the risks of life-threatening complications should be taken into account, hemodynamics should be controlled and if necessary echoCG-investigation should be performed.

Interventional correction of CTO is relatively safe and physiologically justified. With a highly skilled surgeon, the use of modern specialized equipment and careful observation of the appropriate technique of intervention, successful recanalization in more than 80% of cases is feasible. Thorough planning and optimization of the visualization of the target coronary pool can be provided by evaluation of the type of collateral blood flow according to the RAI classification. A knowledge of the blood flow characteristics in each case decreases the risks from intervention, and makes its results more predictable.

Conclusion. The RAI classification of retrograde blood flow which we have established, aimed at optimizing the visualization of postocclusal segments, plays a significant role in evaluation of the possible success of CTO recanalization and can be recommended as a classification variant for the angiographic types of collateral blood flow. It enables assessment of the extent of the lesion and the appropriate selection of an interventional correction technique.

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Referenses

1. *Global atlas on cardiovascular disease prevention and control.* Geneva: World Health Organization; 2011.

2. Guidance on X-ray endovascular surgery of heart and vessels. V. 3. X-ray surgery of coronary heart disease. Pod red. L.A. Bokeriya, B.G. Alekyana [L.A. Bokeriya, B.G. Alekyan (editors)]. Moscow: NTsSSKh im. A.N. Bakuleva RAMN; 2008.

3. Stone G.W., Kandzari D.E., Mehran R., et al. Percutaneous recanalization of chronically occluded coronary arteries. A Consensus document. Part I. *Circulation* 2005; 112: 2364–2372, http://dx.doi.org/10.1161/CIRCULATIONAHA.104.481283.

4. Grantham J.A., Marso S.P., Spertus J., et al. Chronic total occlusion angioplasty in the United States. *JACC Cardiovasc Interv* 2009; 2(6): 479–486, http://dx.doi.org/10.1016/j.jcin.2009.02.008.

5. Osiyev A.G., Biriukov A.V., Redkin D.A., Grankin D.S., Marchenko A.V., Vereshchiagin M.A., Kretov Ye.I. A coronary loop technique without antegrade wireguide during retrograde recanalization of coronary arteries. *Patologiya krovoobrashcheniya i kardiokhirurgiya* 2009; 3: 59–62.

6. Saito S. Progress in angioplasty for chronic total occlusions. *Catheter Cardiovasc Interv* 2010; 76(4): 541–542, http://dx.doi.org/10.1002/ccd.22773.

7. Weisz G., Moses J.W. Contemporary principles of coronary chronic total occlusion recanalization. *Catheter Cardiovasc Interv* 2010; 75(Suppl 1): S21–S27, http://dx.doi.org/10.1002/ccd.22382.

8. Ruzanov I.S., Shitikov I.V., Titkov I.V., et al. Klinicheskaya effektivnost' rekanalizatsii khronicheskikh okklyuziy koronarnykh arteriy pri nizkoy fraktsii vybrosa levogo zheludochka. V kn.: *Materialy VI natsional'nogo kongressa terapevtov* [Clinical efficacy of coronary chronic total occlusion recanalization in low left ventricular ejection fraction. In: Proceedings of the VI National Congress of Physicians]. Moscow; 2011; p. 190.

9. Rathore S., Matsuo H., Terashima M., et al. Procedural and in-hospital outcomes after percutaneous coronary intervention for chronic total occlusions of coronary arteries 2002 to 2008: impact of novel guidewire techniques. *JACC Cardiovasc Interv* 2009; 2(6): 489–497, http://dx.doi.org/10.1016/j.jcin.2009.04.008.

10. Morino Y., Kimura T., Hayashi Y., et al. In-hospital outcomes of contemporary percutaneous coronary intervention in patients with chronic total occlusion insights from the J-CTO registry (Multicenter CTO registry in Japan). *JACC Cardiovasc Interv* 2010; 3(2): 143–151, http://dx.doi.org/10.1016/j.jcin.2009.10.029.

11. Morino Y., Abe M., Morimoto T., et al. Predicting successful guidewire crossing through chronic total occlusion of native coronary lesions within 30 minutes: the J-CTO (Multicenter CTO Registry in Japan) score as a difficulty grading and time assessment tool. *JACC Cardiovasc Interv* 2011; 4(2): 213–221, http://dx.doi.org/10.1016/j.jcin.2010.09.024.

12. Rockstroh J., Brown B.G. Coronary collateral size, flow capacity and growth: estimates from the angiogram in patients with obstructive coronary artery disease. *Circulation* 2002; 105(2): 168–173, http://dx.doi.org/10.1161/hc0202.102120.

13. Werner G.S., Ferrari M., Betge S., et al. Collateral function in chronic total coronary occlusions is related to regional myocardial function and duration of occlusion. *Circulation* 2001; 104(23): 2784–2790, http://dx.doi.org/10.1161/hc4801.100352.

14. Veryn V.V., Selyutin S.M., Kachalov S.N. Recanalization of chronic total occlusions of coronary artery: the condition of problem and our experience. *Kreativnaya kardiologiya* 2010; 2: 60–70.

15. Baroldi G., Scomazzoni G. *Coronary circulation in the normal and the pathologic heart.* Washington D.C.: Office of the Surgeon General, Department of the Army; 1967.

16. Rentrop K.P., Cohen M., Blanke H., Phillips R.A. Changes in collateral channel filling immediately after controlled coronary artery occlusion by an angioplasty balloon in human subjects. *J Am Coll Cardiol* 1985; 5: 587–592.

17. Chesebro J.H., Knatterud G., Roberts R., et al. Thrombolysis in Myocardial Infarction (TIMI) Trial, Phase I: a comparison between intravenous tissue plasminogen activator and intravenous streptokinase. Clinical findings through hospital discharge. *Circulation* 1987; 76(1): 142–154.