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Possibilities of the Hybrid Method (Three-Phase Scintigraphy-SPECT/CT-Angiography) in the Diagnosis and Staging of Acute Lower Limb Ischemia

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ABSTRACT Acute lower limb ischemia (ALLI) is a limb threatening condition with high risk of adverse outcomes. The timely and proper diagnosis of the severity of limb ischemia is crucial in selecting the optimal treatment method.

AIM OF STUDY To evaluate the advantages of hybrid imaging in diagnosis of ALLI, patient selection and its severity in order to choose an optimal revascularization method.

MATERIAL AND METHODS We examined 163 patients with grade 1–3A ALLI based on I.I. Zatevakhin et al. classification (2002) on a Discovery 670 NM/CT hybrid device, using X-ray (computed tomographic angiography) and radionuclide method (three-phase scintigraphy/single photon emission computed tomography with osteotropic or perfused radiopharmaceutical).

RESULTS CT angiography accurately showed level of acute occlusion as well as distal arterial blood flow in all ALLI cases, thus allowing optimal choice of possible revascularization. CT angiography findings alone did not allow optimal staging of ALLI, which is essential for choosing an optimal revascularization method and were considered as supplementary. Three-phase scintigraphy allowed to differentiate the degrees of ALLI based on the visual picture and calculated data, while studies with osteotropic radiopharmaceutical 99mTc-PYP provided information on viability of affected tissues showing the areas of muscle necrosis, compared to perfused radiopharmaceutical.

CONCLUSION 1. CT angiography makes it possible to assess in detail the level and severity of occlusive lesions of the arterial system and study the vascular anatomy of the lower limb to resolve the issue of the possibility of revascularization, and also indirectly characterizes the presence of ischemic changes in soft tissues.

2. The radionuclide method (three-phase scintigraphy with an osteotropic radiopharmaceutical/single photon emission computed tomography), performed in addition to computed tomographic angiography, allows not only to detect the presence of ischemic changes in soft tissues, but also to differentiate the degree of acute ischemia of the lower extremities.

3. The hybrid method (three-phase scintigraphy in combination with computed tomographic angiography) contributes to an objective assessment of the state of blood flow in the lower extremities in acute ischemia, both at the main and at the microcirculatory levels.

Keywords: hybrid method, acute lower limb ischemia, CT angiography, impaired tissue perfusion

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EC - elimination coefficient
CC - correlation coefficient
CRA - coefficient of relative accumulation
CTA - computed tomographic angiography
ALLI - acute lower limbs ischemia
RFP - radiopharmaceutical

INTRODUCTION

Acute limb ischemia is a sudden decrease in limb perfusion that threatens its viability and lasts up to 14 days. According to domestic reviews, the number of patients with acute lower limb ischemia reaches 140 patients per million population per year [1]. According to foreign data, there is one case of acute ischemia per 6,000 people annually [2]. Patients with ALLI have a high risk of poor prognosis: the frequency of amputations in this group reaches 10–15% [3]. The mortality rate in acute ischemia reaches 15–20% [4]. The main causes of ALLI are acute thrombosis (40%), embolism (37%), thrombosis of prostheses and areas of endovascular interventions (up to 15%), as well as aneurysm thrombosis and arterial injury [2, 5, 6]. The treatment of ALLI is rapid restoration of blood flow in the ischemic area. The decisive factors determining the outcome and success of treatment are the level of damage to the arterial bed and the degree of tissue ischemia. However, even if there are indications and anatomical possibilities for performing revascularization intervention, the results of treatment do not always correspond to the expected ones, which is caused by different severity of microcirculatory disorders in the ischemic zone. Domestic and foreign recommendations for the management of patients with ALLI indicate computed tomographic angiography (CTA) as the first-line imaging method, and if it is impossible to perform them, ultrasound and contrast magnetic resonance (MR) angiography. For a long time, digital contrast angiography was considered the "gold standard", which made it possible to perform both diagnostic and revascularization manipulations during the intervention, however, this method is invasive and is accompanied by a large number of complications compared to the above methods for studying the vascular bed [7, 8] . These radiation methods characterize the state of the main arteries, but do not take into account the characteristics of tissue blood flow. There are many domestic and foreign publications on the use of the CTA method for diagnosing an occlusive lesion [9–13]. However, in addition to impaired patency of the main arterial trunks, the results of revascularization intervention are directly affected by the state of tissue blood flow [14]. Its study is an important task, since underestimation of the severity of ischemic injury (for example, at the stage of necrosis formation) at the stage of planning surgical treatment can lead to ineffective revascularization, progression of ischemia in the postoperative period, and the development of severe reperfusion injury [15–18]. In domestic and foreign medical literature, there are publications devoted to the use of the radionuclide method in the assessment of acute and chronic ischemia, but they do not consider this method as an auxiliary method for assessing the degree of ALLI [19–22]. The hybrid method, which combines the possibility of sequential CTA and scintigraphy/SPECT (single photon emission computed tomography) on one scanner, allows you to simultaneously solve both problems - to assess the main blood flow and the severity of ischemic tissue damage.

The aim of the study is to analyze the possibilities of the hybrid method in the diagnosis and differentiation of the degrees of ALLI for the choice of treatment tactics and the selection of patients for revascularization.

MATERIAL AND METHODS

In 2018–2021 163 patients with ALLI were examined using the hybrid method: 131 men (80%) and 32 women (20%), the average age of which was 67.8±11.99 years. Patients were grouped depending on the clinical degree of ALLI in accordance with the classification of I.I. Zatevakhina (2002). The group with grade 1–2A ALLI included 90 patients (55%, mean age 66.2 years), 2B — 34 patients (21%, mean age 72.8 years), 2C — 24 patients (15%, mean age 72 .4 years) and 3A, 15 patients (9%, mean age 64.8 years). In 160 patients, ALLI was a manifestation of vascular failure due to atherosclerotic thrombosis or embolism, and in 3 patients, ALLI was caused by trauma with the development of traumatic arterial thrombosis. Conservative treatment was carried out in 118 patients (68 patients with AEI of grade 1–2A; 21 patients with 2B; , 3A - 5).

Studies of both main and tissue blood flow were carried out on a hybrid scanner *Discovery* 670 *NM/CT*, *GE*, USA. Three-phase scintigraphy is a radionuclide method that includes the first passage of the radiopharmaceutical, tissue and delayed (bone) phases. One of two radiopharmaceuticals was used: osteotropic — ^{99m}Tc-pyrfotech intravenously (i.v.) 500 MBq, radiation exposure to the patient — 2.85 mSv), or perfused — ^{99m}Tc-technetril (i.v. 500 MBq, radiation exposure - 4.5 mSv). The distribution of radiopharmaceuticals was assessed by planar scintigrams in the anterior and posterior projections; if necessary, more accurate localization of changes, the study was supplemented with a tomographic mode (SPECT). Perfused radiopharmaceutical allows you to identify the presence and prevalence of zones of hypo- and aperfusion. Osteotropic radiopharmaceutical, in addition, makes it possible to identify areas of aseptic muscle necrosis that form with ALLI, starting from grade 2B. CTA was performed with intravenous administration of an iodine-containing contrast agent (350 mg/ml iodine (I); 1.2–1.5 ml/kg; 3.5–4.5 ml/s), radiation exposure was 9–11 mSv. Radiation studies were performed at the earliest stages of hospitalization in order to clarify the degree of ALLI (according to the severity of microcirculatory disorders), and studies of the state of the main arterial vessels (including the receiving distal vessels) were used to determine treatment tactics. The data were processed using the statistical processing program "Statistics 10.0".

RESULTS

For each of the radiation methods within the framework of the hybrid study, signs were identified that reflect the pathological processes occurring in the ischemic limb, which were used for analysis and statistical processing.

The following (visual and calculated) were attributed to the scintigraphic signs of ALLI:

- the presence of areas of reduced tissue blood flow or the absence of microcirculation (aperfusion) - in the tissue phase, or in both phases of the study and the nature of their distribution (focal or diffuse);
- the presence of zones of radiopharmaceutical hyperfixation (forming necrotic or infiltrative changes);
- calculated indicators - the index of radiopharmaceutical excretion, the index of the ratio of radiopharmaceutical accumulation, as well as the intensity of accumulation in the focus of necrosis with an increase in the coefficient of relative accumulation (CRA) in the bone phase.

Parameters determined by the CT method:

- location and extent of the occlusive lesion of the main vessel and the number of involved segments of the main channel of the limb;
- the presence of contrasting arteries of the lower leg and foot, reflecting the restoration of distal blood flow;
- the presence of a collateral arterial network;
- density of thrombotic masses;
- the presence of infiltrative changes in the soft tissues of the lower limb;
- signs of fatty infiltration of muscles;
- the density of muscle tissue of a healthy and affected limb.

SCINTIGRAPHIC SIGNS OF ALLI

The presence of areas of reduced tissue blood flow and aperfusion

In the examined cohort of patients, only in group 1-2A there was a small proportion (13%: 12 of 90, 12/90) of patients in whom tissue blood flow was preserved in both tissue and bone phases. These patients were classified as grade 1 ALLI as the corresponding clinical picture of acute ischemia was confirmed.

In the remaining 78 patients (87%) of groups 1-2A, as well as in all patients in groups 2B, 2C and 3A, signs of a decrease in tissue blood flow were found. In patients with grade 2A ALLI, hypoperfusion was noted in the tissue phase when blood supply was restored in the bone phase.

Patients with a clinical picture of severe ischemia of ALLI (stage 2B, 2C, 3A) were characterized by a pronounced decrease in tissue blood flow up to its absence (aperfusion) of a focal or diffuse type.

Aperfusion was defined as visual absence of radiopharmaceutical accumulation in 22 of 28 patients (79%) in group 2B and in 21 of 22 patients (95%) in group 2C. In these patients, this sign was noted in the tissue phase with an increase in the accumulation of radiotracer in the bone phase. In group 3A, all patients (13/13, 100%) had diffuse aperfusion in both phases of the study (tissue and bone), which was associated with the absence of microcirculation against the background of necrotic processes, the impossibility of penetration of the radiopharmaceutical into tissues from the capillary vessels, and the termination blood supply and metabolic activity of bone tissue. At the same time, with an increase in the severity of ALLI, a greater number of cases with a proximal level of the absence of microcirculation disorders were noted (Fig. 1).

Fig. 1. Distribution of patients with different proximal levels of aperfusion in groups according to the clinical degree of acute lower limb ischemia

It should be noted that focal aperfusion was observed in 23 out of 90 patients of clinical group 1–2A (26%), which made it possible to recommend changing the degree of ALLI in these patients to a more severe one (2B).

RFP hyperfixation

Scintigraphy with ^{99m}Tc-pyrphotech revealed areas of radiopharmaceutical hyperfixation, which characterize the formation of muscle necrosis or infiltrative changes in soft tissues, which is associated with the pharmacokinetics of the drug and its ability to be involved in phosphorus-calcium metabolism in bone tissue and accumulate in soft tissues in inflammatory areas. changes and areas of necrosis.

At the same time, for the diagnosis of necrotic changes, an important criterion was the calculation of CRA in the focus of hyperfixation of a relatively healthy limb in the tissue and bone phases. The increase in CRA in the bone phase compared to the tissue phase served as a sign of myonecrosis, in contrast to the zones of infiltrative changes, when no increase in CRA was observed.

Areas of hyperfixation were identified in 29 patients (out of 82 examined with an osteotropic drug) from group 1–2A of the degree of ALLI (9/29 were defined as necrotic changes, which corresponded to a more severe degree of ALLI); in 15/28 patients of group 2B (of which 12/15 had necrotic changes), in 21/22 patients of group 2C (in all 21/21 - necrotic changes), in 11/12 patients of group 3A (in all 11/11 - necrotic changes).

Estimated parameters (elimination coefficient and correlation coefficient) for ^{99m}Tc-Pirfotech

The elimination coefficient (EC) of the RFP was calculated as the ratio of the average count of impulses in the leg muscle in the tissue phase (Nbp) to the average count of impulses in the muscle in the bone phase (Nbp):

$$EC = K \times Ntp / Nbp,$$

where K is a coefficient taking into account the decay of ^{99m}Tc and a correction for a time interval of 3 hours.

At the same time, EC differed statistically significantly in groups 1–2A and 2B ($p = 0.0006$), 1–2A and 2C ($p = 0.0000001$), 1–2A and 3A ($p = 0.005$); as well as in groups 2B–2C ($p = 0.0009$).

The ratio of the average count of impulses in the leg muscle in the tissue phase (Nt) to the average count of impulses in the leg bone in the bone phase (Nb) was taken as the correlation coefficient (CC) of accumulation of radiopharmaceuticals:

$$CC = Nt / Nb$$

The calculated CC indicators had a statistically significant difference between groups 1–2A and 2B ($p = 0.0000001$), 1–2A and 2C ($p = 0.0000001$) and 1–2A and 3A ($p = 0.007$), as well as between groups 2B and 2C ($p = 0.012$).

When analyzing the distribution of these signs in the groups, the following scintigraphic signs of ALLI were obtained (Table 1).

From Table 1 it follows that the 1st degree of acute ischemia is characterized by preserved tissue blood flow in both phases of the radionuclide study with possible infiltrative changes; ischemia 2A is characterized by a decrease in tissue blood flow in the tissue phase with possible infiltrative changes; for ischemia 2B - a decrease or absence of tissue blood flow in the tissue phase, but its restoration in the bone phase (with possible infiltrative changes without zones of aseptic necrosis); ischemia 2C is characterized by the same changes (as in 2B), but with the appearance of zones of aseptic necrosis; for 3A — the absence of tissue blood flow from a certain level in both the tissue and bone phases and areas of radiopharmaceutical hyperfixation above the level of complete lack of blood supply and in the demarcation zone (zones of necrosis).

Table 1

Scintigraphic signs of acute lower limb ischemia

The degree of acute ischemia of the lower extremities	Decreased blood flow		Aperfusion		Hyperfixation of a radiopharmaceutical		Necrosis in the area of aperfusion
	tissue phase	Bone phase	TP	BP	Infiltration	Necrosis	
1	–	–	–	–	–/+	–	–
2A	+	–	–	–	–/+	–	–
2B	+	+	+	–	–/+	–	–
2B	+	+	+	–	–/+	+	–
3A	+	+	+	+	-/+ in viable - tissues	–/+ in the demarcation zone	+

Nates: "+" the sign is present, "-" the sign is absent

The visual scintigraphic picture, characteristic of ALLI, is shown in fig. 2.

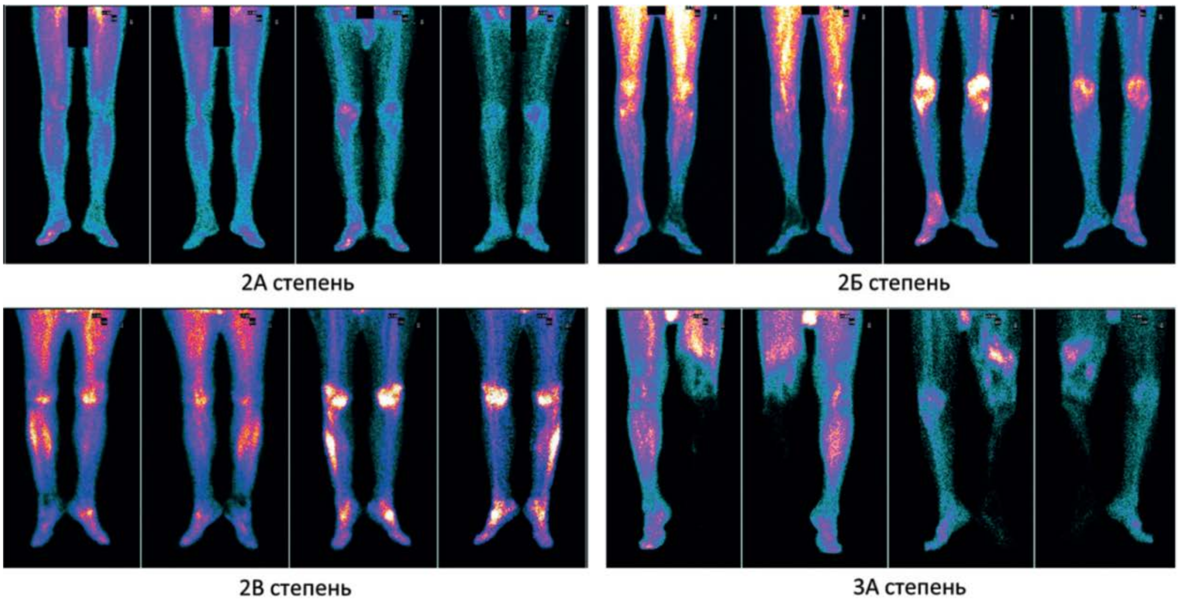

Fig. 2. Visual signs of acute lower limb ischemia based on the scintigraphic method; for each degree of acute ischemia of the lower extremities, scintigrams are presented in the tissue phase in the anterior and posterior projections and the bone phase also in the anterior and posterior projections: grade 2A — reduced accumulation of the radiopharmaceutical in the lower third of the lower leg and foot on the left with redistribution to the bone phase; Grade 2B — decrease in microcirculation from the level of the middle third of the left lower leg and in the foot with an area of aperfusion in the ankle joint with restoration of the accumulation of the radiopharmaceutical in the bone phase; 2B — decreased microcirculation in the distal third of the right lower leg and in the foot with an area of aperfusion in the area of the ankle joint with recovery into the bone phase, as well as an area of necrotic changes in the muscles of the right lower leg with an increase in accumulation into the bone phase; 3A — aperfusion in the tissues of the left limb from the level of the middle of the left thigh with no recovery of accumulation in the bone phase, necrotic changes without the receipt of a radiopharmaceutical, as well as a demarcation area in the form of emerging necrosis with hyperfixation of the radiopharmaceutical in the middle third of the left thigh

The calculated indices had less statistical significance in the differentiation of groups, however, there was a clear trend towards an increase in the values of EC and a decrease in the values of CC with aggravation of the severity of ischemia. Medium values indices presented in Table 2.

Table 2

The distribution of the values of the elimination index and the ratio index depending on the degree of acute ischemia of the lower extremities in the examined sample of patients

The degree of acute ischemia of the lower extremities	Elimination coefficient	Correlation coefficient
1–2A	1.44±0.53	0.59±0.17
2B	1.05±0.49	0.8±0.13
2B	0.62±0.43	1.08±0.04
3A	0.85±0.67	0.89±0.36

Table 2 shows that EC (the ratio of the average count of impulses in the muscle in the tissue phase to the average count of impulses in the muscle in the bone phase) decreases with the aggravation of the degree of ischemia, and CC (the ratio of the average count of impulses in the muscle to the average count of impulses in the bone in the bone phase) increases.

Using a perfused preparation of ^{99m}Tc-technetrile: 8 with clinical grade ALLI 1–2A, 6 with 2B, 2 with 2C, and 2 with 3A. At the same time, studies with this radiopharmaceutical were inferior in informational content to the osteotropic drug, since its pharmacokinetics do not allow the identification of zones of necrotic changes in soft tissues and does not make it possible to clearly differentiate between severe degrees of ALLI (2B, 2C, 3A).

SIGNS OF ALLI DETERMINED BY THE CT METHOD

As part of the hybrid study, all patients underwent CTA. Consecutive performance of two X-ray studies (X-ray and radionuclide) on the same device made it possible to avoid additional time costs and logistical measures for moving patients (taking into account the severity of the pain syndrome, such patients are usually transported on a gurney accompanied by medical staff), and also made it possible to compare images (CTA and SPECT) for accurate localization of pathological changes in soft tissues.

The following distribution of the signs indicated above, detected by the CTA method, was revealed.

The presence and location of an occlusive lesion of the main vessel and the number of involved segments of the main channel of the lower limb

All patients (100%) had an occlusive lesion of the main arteries of the lower extremities.

The following segments of the arterial vessels were studied, based on the blood supply systems and the order of branching of the arteries: aortoiliac (distal aorta, common and external iliac arteries), femoral (common femoral artery, deep femoral artery - for blood supply to the entire lower limb or thigh), and distal (superficial femoral artery, popliteal artery and lower leg arteries - for blood supply to the knee, lower leg and foot area). With ischemia of degrees 1–2A–2B–2C, an increase in the number of “higher” occlusions was noted as the severity of ischemia increased (Fig. 3). At grade 3A in the examined group, there was a trend towards a decrease in the number of proximal and an increase in the number of peripheral occlusions.

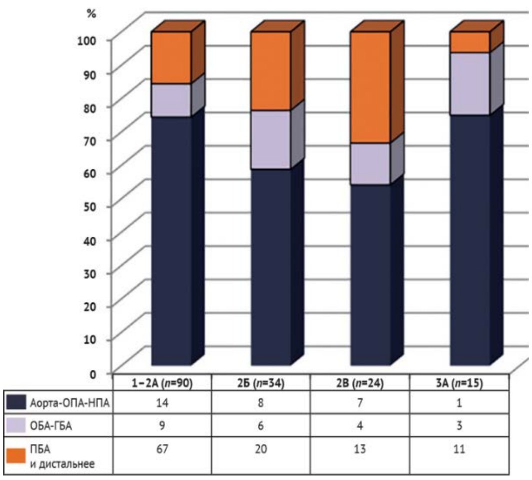

Fig. 3. Proximal levels of occlusion according to computed tomography-angiography in patients with various degrees of acute lower limb ischemia

Notes: DFA — deep femoral artery; EIA— external iliac artery; CFA — common femoral artery; CIA — common iliac artery; SFA — superficial femoral artery

There was no statistically significant difference between the groups in the prevalence of occlusive lesions, taking into account the involved segments. The quantitative distribution by levels of the arterial bed involved in the occlusive process in each group is shown in the diagram (Fig. 4).

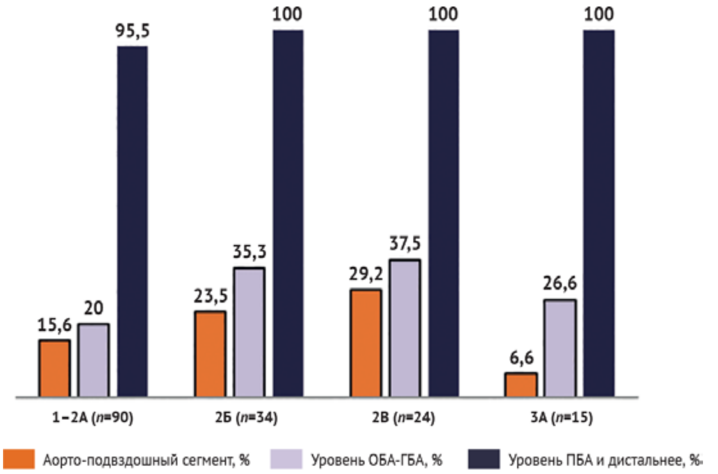

Fig. 4. The involvement of various levels of the arteries in groups 1–3A according to the degree of acute lower limb ischemia in the occlusive process

Notes: DFA - deep femoral artery; CFA - common femoral artery; SFA - superficial femoral artery

The length of the area of occlusion of the main vessel

There was a predominance of the number of "long" occlusions (more than 30 cm) with an increase in the severity of ALLI (from 48% with degree 1–2A to 93% with degree 3A), which is probably due to the rapid addition of secondary thrombosis and lengthening of the initially short occluded area against the background of blood stasis in front of the occlusion zone, as well as distal to the occluded segment. This process is facilitated by the absence of collateral blood flow and impaired microcirculation against the background of ischemic damage and changes in the rheological properties of blood during intoxication with myonecrosis products.

Restoration of contrast in the distal vessels and the presence of a collateral network

There were no statistically significant differences in the number of cases of restoration of blood flow in the distal bed (complete or partial) in groups 1–2A and 2B, 2B and 2C (p = 0.062 in both cases). At the same time, the data between groups 1–2A and 3A, 1–2A and 2B, 2B and 3A differed statistically significantly (p=0.04). Schematically, the percentage distribution of options for restoring blood flow is shown in the graph (Fig. 5).

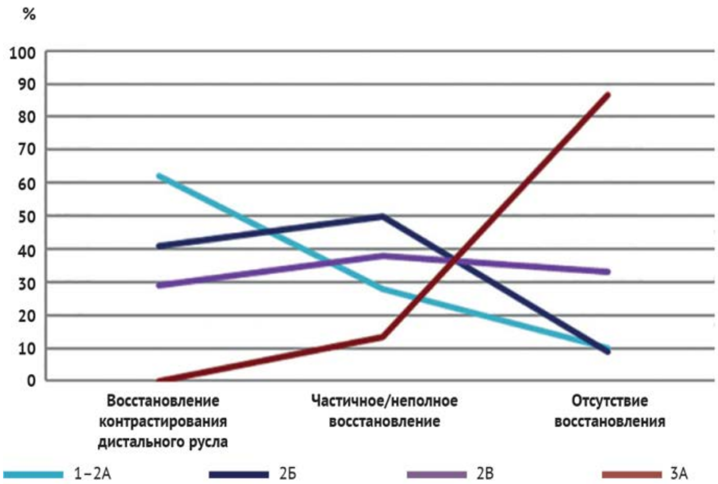

Fig. 5. Restoration of contrast distal to the occlusion zone according to computed tomography-angiography data

Availability of collateral network

A developed collateral network was more often seen in ischemia 1–2A and 2B, while a collateral network in limbs with doubtful viability and signs of gangrene formation (grades 2B and 3A) was present in only 10 patients. This could be due to the rapid progressive increase in ischemia during occlusion in the "unprepared" vascular system. At the same time, with a long-term atherosclerotic process and the gradual development of arterial lumen obstruction, a collateral network has time to form around the occlusion site (Fig. 6).

Fig. 6. Computed tomography-angiography, three-dimensional reconstruction, frontal plane: there is a bilateral occlusive lesion of the superficial femoral artery, occlusion of the femoral popliteal shunt on the left, occlusion of the middle and distal third of the deep femoral artery on the right; bilateral collateral network in the soft tissues of the thigh due to the branches of the deep artery of the thigh

Density of muscle tissue of a healthy and affected limb

The density of muscle tissue was measured in the same zones of equal size on the affected and contralateral (conditionally "healthy") limbs:

- in the thickness of the adductor muscles at the level of the thigh distal to the gluteus maximus muscle,
- in the muscles of the anterior part of the upper third of the lower leg (since the muscles of the anterior compartment of the lower leg are more sensitive to ischemic damage).

Density values in a healthy and affected limb at the level of the thigh and lower leg are shown in the diagrams (Fig. 7, 8).

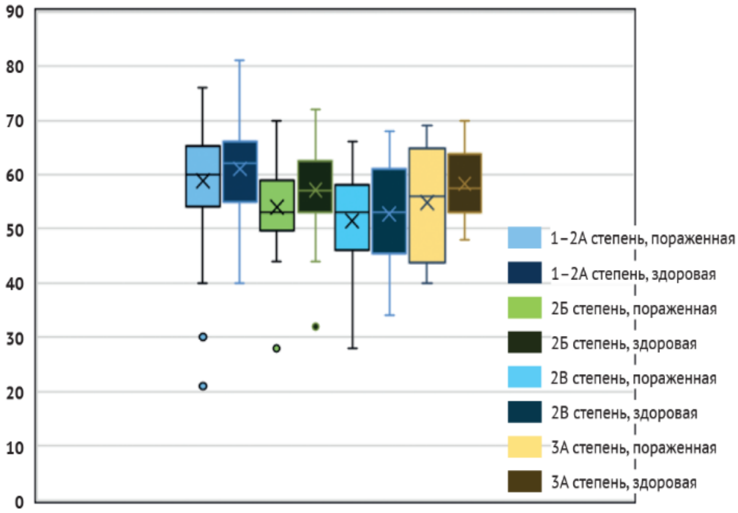

Fig. 7. Distribution of thigh muscle density values in healthy and affected limbs depending on the degree of acute lower limb ischemia

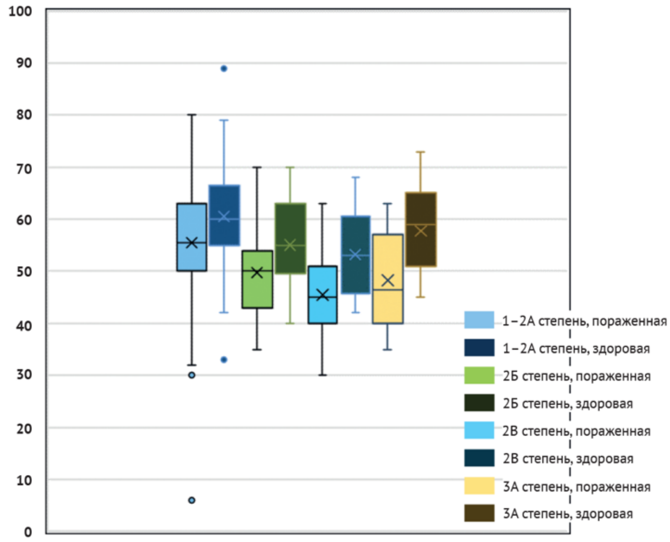

Fig. 8. Distribution of the density values of the leg muscles of a healthy and affected limb depending on the degree of acute lower limb ischemia

The data presented in Fig. 7 and 8 demonstrate the presence of a difference in density values in the subgroups of the healthy and affected limb when measured at the level of the lower leg. At the level of the thigh, this difference was absent or was statistically insignificant. This fact can be explained by the blood supply to the thigh muscles from the unaffected deep femoral artery during infrainguinal occlusions (against the background of their predominance in the general sample of patients).

Infiltrative changes in soft tissues are caused by the phenomena of ischemia and aseptic inflammation and are manifested by edema of cells and intercellular spaces and leukocyte inflammatory infiltration. In CTA, they were characterized by signs of edema of the subcutaneous adipose tissue of the lower extremities and adipose tissue of the intermuscular spaces with an uneven increase in its density, heaviness, an increase in the volume of soft tissues and "smoothness" of the intermuscular fatty layers. In addition, the signs of edema and infiltrative changes in the muscles included the loss of their fibrous structure and the appearance of homogeneity with “stressed” tendon elements. When measuring the density of muscle tissue in these cases, as a rule, reduced (compared to a healthy limb) values were obtained. In the examined groups, there was an increase in the number of patients with infiltrative changes in soft tissues and signs of their edema in severe ischemia (2B, 2C, 3A). Relevant data presented in Table 3.

Table 3

Number of patients with soft tissue changes (infiltrative changes, edema) revealed by computed tomography angiography

Degree of ischemia	Number of cases	Share in the group, %
1–2A (*n* =90)	29	32
2B (*n* =34)	16	47
2V (*n* =24)	11	46
3A (*n* =15)	11	73

Signs of substitutive fatty infiltration of muscles are not a direct sign of acute ALLI and reflect the presence of chronic arterial insufficiency of muscle tissue or a previous episode of ALLI, against which the typical structure of muscle fibers is lost and they are replaced by adipose tissue. The presence of fatty infiltration of the muscles of the affected limb, regardless of the level of occlusion, was assessed, while signs of fatty infiltration were present in 34% of patients from group 1–2A, in 50% of patients in group 2B, in 42% of patients with 2C, and in 40% of patients with grade 3A ALLI.

The density of thrombotic masses, measured by CTA, had no statistically significant differences in the groups according to the degrees of ALLI and was in the range of 27 Hu and 77 Hu. In addition, the values of thrombus density in the same patient differed significantly when measured at different levels of the occlusion zone.

When systematizing the signs of CT imaging, depending on the degree of ALLI, the following data were obtained (Table 4).

Table 4

Distribution of signs detected by computed tomography-angiography depending on the degree of acute lower limb ischemia

The degree of acute ischemia of the lower extremities	Angiographic features							tissue signs	
	State of the main channel, *n* (%)	Recovery of contrast, *n* (%)	Presence of a collateral network, *n* (%)	Occlusion length, *n* (%)	Proximal level of occlusion			The density of the muscle tissue of the lower leg of the diseased limb	Infiltrative changes, *n* (%)
					SFA and distal, *n* (%)	CFA-DFA, *n* (%)	aorta – CIA-EIA *n* (%)		
1–2A (*n* =90)	occlusion	56 (62)	72 (80)	43 (48)	67 (74)	9 (10)	14 (16)	55.52±11.1	29 (32)
2B (*n* =34)	occlusion	14 (41)	23 (68)	24 (70)	20 (59)	6 (18)	8 (24)	49.71±7.9	16 (47)
2B (*n* =24)	occlusion	7 (29)	8 (33)	18 (75)	13 (54)	34 (17)	8 (29)	45.43±9.0	11 (46)
3A (*n* =15)	occlusion	0	2 (13)	14 (93)	11 (73)	3 (20)	1 (7)	48.29±9.2	11 (73)

Notes: DFA— deep artery of the thigh; EIA — external iliac artery; CFA — common femoral artery; CIA — common iliac artery; SFA — superficial femoral artery

From Table 4 it follows that, unlike scintigraphy, the CTA method did not reveal clear criteria for distinguishing between the degrees of ALLI. All patients had occlusion of the main arterial vessel as the cause of acute ischemia. There was a correlation between the severity of ischemia and the presence of restoration of contrast in the arterial system distal to the occlusion area. In more severe ALLI, there was a poor or no collateral network, a significant length of occlusion, a greater number of involved vascular segments, and among tissue signs, a lower density of muscle tissue compared to a healthy limb, a greater severity of infiltrative changes and edema. These signs do not allow identifying the degree of ALLI, but can be used as additional ones to assess the severity of acute ischemia.

CONCLUSION

Hybrid technology helps in the complex diagnosis of lower limb blood flow disorders at the main and microcirculatory levels to determine the cause and severity of acute ischemic limb injury. Its use contributes to the choice of optimal treatment tactics, resolving the issue of the possibility and methods of revascularization to save a limb or reduce the level of amputation, as well as timely planning of detoxification.

FINDING

1. Computed tomographic angiography makes it possible to assess in detail the level and severity of occlusive lesions of the arterial bed and study the vascular anatomy of the lower limb to resolve the issue of the possibility of revascularization, and also indirectly characterizes the presence of ischemic changes in soft tissues.
2. The radionuclide method (three-phase scintigraphy with an osteotropic radiopharmaceutical/single photon emission computed tomography), performed in addition to computed tomographic angiography, allows not only to detect the presence of ischemic changes in soft tissues, but also to determine the degree of acute ischemia of the lower extremities 1-3A.
3. The hybrid method (three-phase scintigraphy in combination with computed tomographic angiography) contributes to an objective assessment of the state of blood flow in the lower extremities in acute ischemia, both at the main and microcirculatory levels.

REFERENCES

1. Dormandy J, Heeck L, Vig S. Acute limb ischemia. *Seminar Vasc Surg*. 1999;12(2):148–153. PMID: 10777242
2. *Natsional'nye rekomendatsii po diagnostike i lecheniyu zabolevaniy arteriy nizhnikh konechnostey.* Moscow; 2019. (In Russ.) Available at: https://www.angiolsurgery.org/library/recommendations/2019/recommendations_LLA_2019.pdf [Accessed Oct 12, 2022]
3. Dua A, Lee C. Epidemiology of Peripheral Arterial Disease and Critical Limb Ischemia. *J Techniq Vasc Interv Radiol* . 2016;19(2):91–95. PMID: 27423989 https://doi.org/10.1053/j.tvir.2016.04.001
4. Kharazov AF, Kalyev AO, Isaev AA. PAD distribution in Russian Federation. *Pirogov Russian Journal of Surgery.* 2016;(7):58–61. (In Russ.). https://doi.org/10.17116/hirurgia2016758-61
5. Foroni Casas AL. Acute Arterial Embolism of the Lower Limb. In: Stawicki SP, Swaroop M, Firstenberg MS. (eds.) *Embolic Diseases»– Evolving Diagnostic and Management Approaches*. Norderstedt, Germany: BoD – Books on Demand; 2020. Ch.5. https://doi.org/10.5772/intechopen.84396 Available at: https://www.intechopen.com/chapters/66190 [Accessed Oct 12, 2022].
6. Padberg FT, Hobson RW II. Fasciotomy in acute limb ischemia. *Semin Vasc Surg.* 1992;5:52.

7. Kalogeris T, Baines CP, Krenz M, Korthuis RJ. Cell Biology of Ischemia/Reperfusion Injury. *Int Rev Cell Mol Biol.* 2012;298:229–317. PMID: 22878108 https://doi.org/10.1016/B978-0-12-394309-5.00006-7
8. Nebylitsin YS, Lazuko SS, Kut'ko EA. Ischemia-Reperfusion Syndrome of Lower Limbs. *Vitebsk Medical Jornal.* 2018;17(6):18–31. (In Russ.) https://doi.org/10.22263/2312-4156.2018.6.18
9. Marshalov DV, Petrenko AP, Glushach IA. Reperfusion Syndrome: Notion, Definition, Classification. *Circulation Pathology and Cardiac Surgery*. 2008;3:67–72. (In Russ.)
10. Valko M, Leibfritz D, Moncol J, Cronin MT, Mazur M, Telser J. Free radicals and antioxidants in normal functions and human disease. *Int J Biochem Cell Biol*. 2007;39(1):44–84. PMID: 16978905
11. Chernyavsky MA, Neverov VA, Susanin NV, Soloviev VA, Belova YuK, Kazantsev AN. Revascularization in Lesion of Arteries of the Aortoiliac Arterial Segment. Literature Review and Clinical Examples. *Russian Sklifosovsky Journal Emergency Medical Care.* 2021;10(4):760–768. (In Russ.) https://doi.org/10.23934/2223-9022-2021-10-4-760-768
12. Prozorov SA, Belozerov GE. A Current Role of Endovascular Techniques in the Diagnosis and Treatment of Patients With Acute Aortic Pathology. *Russian Sklifosovsky Journal Emergency Medical Care*. 2013;(1):46–49. (In Russ.)
13. Fleischmann D, Hallett RL, Rubin GD. CT Angiography of Peripheral Arterial Disease. *J Vasc Interv Radiol*. 2006;17(1):3–26. PMID: 16415129 https://doi.org/10.1097/01.RVI.0000191361.02857.DE
14. Horehledova B, Mihl C, Milanese G, Brans R, Eijsvoogel NG, Hendriks, et al. CT Angiography in the Lower Extremity Peripheral Artery Disease Feasibility of an Ultra-Low Volume Contrast Media Protocol. *Cardiovasc Intervent Radiol*. 2018;41(11):1751–1764. PMID: 29789875 https://doi.org/10.1007/s00270-018-1979-z
15. Lim JC, Ranatunga D, Owen A, Spelman T, Galea M, Chuen J, et al. Multidetector (64+) computed tomography angiography of the lower limb in symptomatic peripheral arterial disease: Assessment of image quality and accuracy in a tertiary care setting. *J Comput Assist Tomogr*. 2017;41(2):327–333. PMID: 27753721 https://doi.org/10.1097/RCT.0000000000000494
16. Kudryavtseva AV, Trufanov GE, Erofeeva AA. Komp'yuterno-tomograficheskaya angiografiya v diagnostike obliteriruyushchikh zabolevaniy arteriy nizhnikh konechnostey. *REJR*. 2012;2(S2):291–292. (In Russ.) Available at: http://www.rejr.ru/past-issues.html [Accessed Oct 12, 2022].
17. Shorina YaE, Filippova IA. Spiral'naya komp'yuternaya tomografiya s angiografiey v diagnostike i planirovanii taktiki lecheniya zabolevaniy arteriy nizhnikh konechnostey. *REJR*. 2012;2(S2):674–674. (In Russ.) Available at: http://www.rejr.ru/past-issues.html [Accessed Oct 12, 2022].
18. Kudryashova NY, Sinyakova OG, Mikhaylov IP, Migunova EV, Leshchinskaya OV. Radionuclide Patterns of Ischemia in Acute Occlusive Diseases of Main Arteries of Lower Extremities. *Russian Sklifosovsky Journal of Emergency Medical Care*. 2019;8(3):257–265. https://doi.org/10.23934/2223-9022-2019-8-3-257-265
19. Savel'ev VS, Zatevakhin II, Frolov VK, Vagner TE. Kriterii stepeni ishemii i otsenka zhiznesposobnosti tkaney nizhnikh konechnostey pri ostroy arterial'noy neprokhodimosti. *Vestnik AMN SSSR.* 1980;5:74–81. (In Russ.)
20 Svetlov KV, Svirshchevskij EB, Trofimov EI, Filippov VV, Adrianov SO, Rodionova TV. Estimation of regional blood flow in reimplanted segments of upper extremity. *Pirogov Russian Journal of Surgery*. 2015;(7):49–56. (In Russ.). https://doi.org/10.17116/hirurgia2015749-56
21. Matsuo S, Nakajima K, Kinuya S. Evaluation of Cardiac Mitochondrial Function by a Nuclear Imaging Technique using Technetium-99m-MIBI Uptake Kinetics. *Asia Ocean J Nucl Med Biol*. 2013;1(1):39–43. PMID: 27408841 https://doi.org/10.7508/aojnmb.2013.01.008
22. Blebea J, Kerr JC, Franco CD, Padberg FT Jr, Hobson RW 2nd. Technetium 99m pyrophosphate quantitation of skeletal muscle ischemia and reperfusion injury. *J Vasc Surg.* 1988;8(2):117–124. PMID: 2840521 https://doi.org/10.1016/0741-5214(88)90397-7

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