Research Article

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Computed Tomography Criteria for Differential Evaluation of True and False Lumens in Aortic Dissection

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THE AIM OF STUDY Based on computed tomography data, to determine the most characteristic criteria for true lumen (TL) and false lumen (FL) in aortic dissection. To identify the relationship of the studied features with the stage of aortic dissection.

MATERIALS OF THE STUDY Computed tomography (CT) data of 115 patients diagnosed with aortic dissection (AD) who were treated at the N.V. Sklifosovsky Research Institute for Emergency Medicine were analyzed. The average age of the patients was 54.5 years (median — 56 years), men predominated in the studied group. AD types according to the De Bakey classification were distributed as follows: Type I — in 47% of patients, Type II — in 16.5%, Type III — in 36.5%. Dissection in the acute stage occurred in 62% of the patient, in the subacute — in 16%, in the chronic — 22%.

RESULTS In the studied group, FL in all cases prevailed over the TL by size, regardless of the stage and type of AD. Analysis of lumen ratio showed that in 63.55% of patients, FL occupied 75% or more of the aortic cross-sectional area.

Location of FL: at the level of the ascending aorta, along the right and anterior walls of the aorta — 94.5%; in the descending thoracic aorta, along the posterior and left walls — 84%; in the abdominal aorta, along the posterior and left walls — 70%. Calcifications of the non- dissected part of the aortic wall, as a sign of a true lumen, were found in 59.1%. There was no correlation between calcification and the AD stage. Partial thrombosis of one of the lumens was detected in 59% (in FL — 85%, in TL — 13%, thrombosis of both lumens — 2%). The beak signs occurred in 85% of patients with AD, however, it was significantly more often detected in patients with acute and subacute AD stages than in the chronic stage ($p<0.001$). The cobweb sign was found in one third of patients with AD, however, it was statistically significantly more often determined in patients in acute and subacute stages ($p<0.05$).

CONCLUSION CT is reasonably considered a highly informative method of diagnosing AD. The signs of true and false lumen presented in the work, as well as their combination, make it possible to perform a quick and error-free marking of the aortic lumen with a high degree of probability. A number of the described CT signs correlate with the stage of AD.

Key words: computed tomography, aortic dissection, false lumen, true lumen

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AD – aortic dissection
CIA – common iliac arteries
CT – computed tomography
FL – false lumen
TL – true lumen

Aortic dissection (AD) is a sudden formation of a defect in the inner layer of the aortic wall with subsequent penetration of the blood flow into the degeneratively altered middle layer [1,2].

The problem of diagnosing and treating AD has a rather long history, however, given the high numbers of complications and mortality in patients with this disease, the relevance of further research has remained to this day [3, 4]. Computed tomography (CT) characterized by excellent spatial and temporal resolution is a reasonable method of choice for the diagnosis of acute and chronic aortic lesions, including dissection. The modern literature provides numerous data on the high informational content and accuracy of CT, which approach almost 100% [5–9].

The main sign of AD according to CT data is the visualization of the detached intima in the aortic lumen with the formation of an additional pathological channel - the false lumen (FL). Depending on the location and extent of the lesion, the dissection is divided according to generally accepted classifications [10–12]. Notably, the false lumen can function, that is, be without signs of thrombosis, and in some cases be partially or completely thrombosed.

After AD is diagnosed according to CT data, the radiologist has to describe this pathology in detail, including the prevalence of the process, the presence and localization of fenestrations (tears) of the intima, the assessment of the TL and FL, and also indicate from which of the lumens the main aortic branches originate [13, 14].

As a rule, differentiating the true lumen from the false lumen on CT does not cause great difficulties, and it is often possible to trace the transition of the unchanged aortic area to the dissection zone. However, in a number of cases, difficulties in such labeling of lumens arise either with type I dissections, or in case of multichannel dissection. Accurate determination of intimal fenestrations' localization, as well as the state of the both lumens, is extremely important when planning endovascular treatment. To date, at least 10 different signs have been known that allow differentiating the true lumen from the false one according to CT data [1, 14–17]. Among these signs, there are both the most common and typical, and less characteristic and even doubtful.

Aim of the study: According to computed tomography data, to identify the most characteristic criteria for the true and false lumens of the aorta in case of its dissection. To determine the relationship of the studied features with the stage of dissection.

RESEARCH MATERIAL

We studied CT data of 115 patients with a confirmed diagnosis of aortic dissection, who were treated at the N.V. Sklifosovsky Research Institute for Emergency Medicine. Among the patients, men predominated (78%). The median age was 54.5 years (from 27 to 86 years; median, 56 years). Types of AD according to the DeBakey classification were distributed as follows: type I — 54 patients (47%), type II — 19 (16.5%), type III — 42 (36.5%). Dissection in the acute stage (up to two weeks from the onset) was observed in 71 patients (62%), in the subacute (from 2 weeks to 2 months) – in 18 (16%), in the chronic (more than 2 months) – in 26 (22%) (Table 1).

Table 1

Distribution of patients by type of aortic dissection and by disease stages

Stages of aortic dissection*	DeBakey classification of aortic dissection			Total
	I	II	III	
Acute	43 (61%)	10 (14%)	18 (25%)	71 (61.7%)
Subacute	4 (22%)	7 (39%)	7 (39%)	18 (15.7%)
Chronic	7 (27%)	2 (8%)	17(65%)	26 (22.6%)
Total	54(47%)	19 (16.5%)	42(36.5)	115(100%)

Notes: * — stages of the disease: acute — up to 2 weeks old; subacute — from 2 weeks to 2 months; chronic — more than 2 months

CT scans were performed using 64- and 160-slice CT scanners. The aorta was examined along its entire length, including the areas of the neck and pelvis. All studies were carried out with intravenous bolus administration of an iodine-containing contrast agent in the standard volume (100 ml).

Based on the CT data, the following features were evaluated: 1) the size of the true and false lumens; 2) the location of the lumens at three anatomical levels (ascending, thoracic, abdominal); 3) the presence of focal calcification of the aortic wall at the level of dissection; 4) the presence of thrombosis of one of the lumens; 5) the presence of the beak sign); 6) the presence of the cobweb sign; 7) variations in the branching pattern of the celiac trunk; 8) variations in the branching pattern of the superior mesenteric artery; 9) variations in the branching pattern of the renal arteries; 10) the presence of transition of the dissection to the iliac arteries.

The ratio TL/FL was estimated based on the measurement of the size and area of each of them at one or more anatomical levels of the aorta. As a result of the assessment, the average values of changes (the worst values of changes) were taken for calculation.

The data were collected in a table using Microsoft Excel 2010. Statistical data processing was carried out using the STATISTICA 7.0 software tool. Chi-squared and Fisher's exact test were used to compare the observed instances of the considered signs in groups according to the level of localization, type and stage of aortic dissection.

RESULTS

In the studied group of 115 patients, the false lumen visually prevailed in size over the true lumen in all the cases, regardless of the stage and type of AD. The analysis of the lumen ratio showed that in 42 patients (36.5%), the FL occupied from 50% to 75% of the cross-sectional area of the aorta, and in the remaining 73 (63.55%) patients, it occupied 75% or more (Table 2). Thus, in 63.5% of patients, severe TL compression was found.

Table 2

Size ratio of true lumen and false lumen of the aorta, depending on dissection stage

Stages of aortic dissection	False lumen under 75%	False lumen over 75%	*p*	Total
Acute (1)	15 (21.1%)	56 (78.9%)	$p_{1,2}$=0.043 $p_{1,3}$<0.001	71 (100%)
Subacute (2)	8 (44.4%)	10 (55.6%)	$p_{2,3}$=0.055	18 (100%)
Chronic (3)	19 (73%)	7 (27%)		26 (100%)
Total	42	73	$p_{1+2,3}$<0.001 $p_{1,2+3}$<0.001	115

Notes: $p_{1,2}$ — significance level when comparing the frequency of observation of a false lumen in the group with acute and subacute AD stages, $p_{1,3}$ — for the groups with acute and chronic AD stages, $p_{2,3}$ — for the groups with subacute and chronic AD stages, $p_{1+2,3}$ — for the acute AD group combined with subacute AD group and chronic AD group, $p_{1,2+3}$ — for the acute AD group and subacute AD group combined with chronic AD group

According to the results of the analysis reflected in the Table 2, we can conclude that the number of observations with the FL area over 75% is more common in the group of patients with acute AD stage. The results obtained differ statistically significantly in relation to groups of patients with acute and subacute AD stage, as well as with acute and chronic AD stages (p=0.043 and p<0.001, respectively), groups with subacute and chronic AD stages do not differ from each other (p=0.055).

LOCATION OF THE AORTIC LUMENS

Localization of FL at various levels is presented in Table 3. At the level of the ascending aorta (in 73 patients with type I and II AD), the FL was most often located along the right and anterior walls (94.5%). The left and posterior walls were involved in dissection much less frequently (2.8%). Circular detachment of the intima in the ascending section was found in 2 cases (2.7%).

Table 3

Localization of the false lumen at different levels of the aorta

Localization of the false lumen	Sections of the aorta		
	Ascending aorta	Descending thoracic aorta	Abdominal aorta
Anterior	**16 (21.9%)**	4 (4.2%)	1 (1.05%)
Posterior	1 (1.4%)	**35 (36.8%)**	**36 (37.5%)**
Right	**53 (72.6%)**	11 (11.6%)	27 (28.1%)
Left	1 (1.4%)	**45 (47.4%)**	**31 (32.3%)**
Circular	2 (2.7%)	–	1 (1.05%)
Total	**73 (100%)**	**95 (100%)**	**96 (100%)**

Descending thoracic aortic dissection was detected in 95 patients with type I and III AD. The FL was located along the posterior and left aortic walls in 80 cases (84%). The anterior and right walls were involved in 4 (4%) and 11 (12%) cases, respectively.

Abdominal aortic dissection was detected in 96 patients. The FL was more often located along the posterior and left aortic walls (70%). The right wall was involved in 28%, and the anterior wall was involved in only 1% of cases.

AORTIC WALL CALCIFICATION

Focal calcification of the aortic wall and iliac arteries, characteristic of atherosclerosis, was detected in 75 patients with the mean age of 54.5 years (median 56 years). It is known that calcifications are located on the inner layer of the aortic wall - the intima. In case of AD, calcifications can move along with the dissected intima into the lumen of the vessel, or stay fixed in the unaffected area, that is, in the wall of the true lumen (Fig. 1).

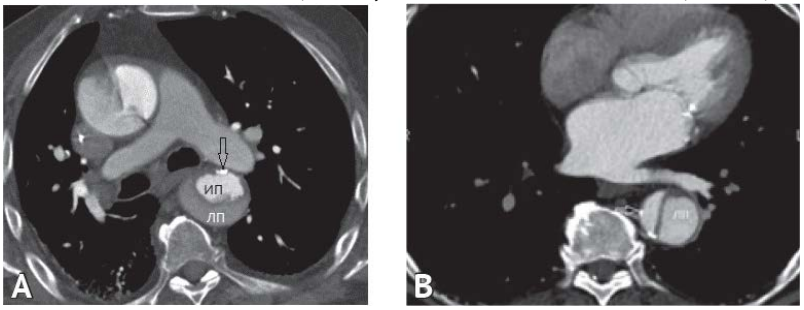

Fig. 1. Contrast enhanced computed tomography of patients with aortic dissection. In the descending aorta, calcifications of the non-dissected area (arrows) are determined, which is the wall of the true lumen (ИП). False lumen (ЛП)

Among the studied patients, calcifications of the non-dissected portion of the aortic wall, as a sign of the true lumen, were found in 68 cases. Calcifications in the wall of the false lumen were found in 2 patients with chronic AD. In the remaining 5 patients, calcifications were located only in the dissected area of the intima (Table 4).

Table 4

Localization of calcifications in the aortic wall in aortic dissection

Location of calcifications	Number of observations	%	Calcification – yes
Calcification – no	40	34.8	–
True lumen	**68**	**59.1**	90.67%
False lumen	2	1.7	2.67%
Dissected intima	5	4.4	6.66%
Total	115	100	100

When comparing all three groups according to the stage of the disease, statistical difference between the incidence of calcification of the TL wall was not revealed (for acute and subacute stages p=0.463, for acute and chronic stages p=0.067, for subacute and chronic stages p=0.883). Other options were not compared in the absence of such cases.

LUMINAL THROMBOSIS

In all cases of thrombosis, AD is characterized by the acute formation of an additional pathological lumen and a change in normal hemodynamics in the aorta and its main branches. Blood clot formation in one of the aortic lumens can be due to several reasons. FL thrombosis occurs as a response to a direct impairment of the aortic wall integrity in combination with the activation of hemocoagulation mechanisms. Another cause of thrombosis may be a decrease in velocity and the appearance of turbulent blood flow in the dilated FL. TL thrombosis is formed much less frequently as a result of a complex of factors, one of which is its pronounced compression from the FL.

Partial thrombosis of one of the lumens was determined in 68 examined patients (59% of all examined patients). In this group, FL thrombosis was detected in 85% of cases, TL thrombosis - in 13%, and thrombosis of both lumens – in less than 2%. At the same time, it was noted that 8 out of 9 cases of TL thrombosis were in patients with acute AD, and 1 case in a patient with the subacute AD stage. The situation is different in case of chronic AD, where thrombosis in all cases was localized only in the FL (Table 5).

Table 5

Localization of luminal thrombosis depending on the stage of aortic dissection

Luminal thrombosis (n=68)	Aortic dissection stage			*n* (%)
	Acute	Subacute	Chronic	
True lumen	8 (11.8%)	1 (1.47%)	0	9 (13.2%)
False lumen	26 (38%)	12 (17.6%)	20 (29.4%)	58 (85.3%)
Combination of true and false lumens	1 (1.47%)	0	0	1 (1.5%)
Total	35	13	20	68 (100%)

Notes: ИП — true lumen; ЛП — false lumen

When comparing the three groups according to the stage of the disease, statistically significant difference between the incidence of FL thrombosis was found for acute and chronic AD stages (p=0.013) and for subacute and chronic AD stages (p=0.008). The difference was not statistically significant for acute and subacute AD stages (p=0.171). The incidence of TL thrombosis for the acute and subacute AD stages was not statistically significant (p=0.231). Other options were not compared in the absence of such cases.

The beak sign of AD, which is an acute angle between the adventitia and the detached inner layer (intima-media) on CT angiograms, is a characteristic symptom for the FL (Fig. 2).

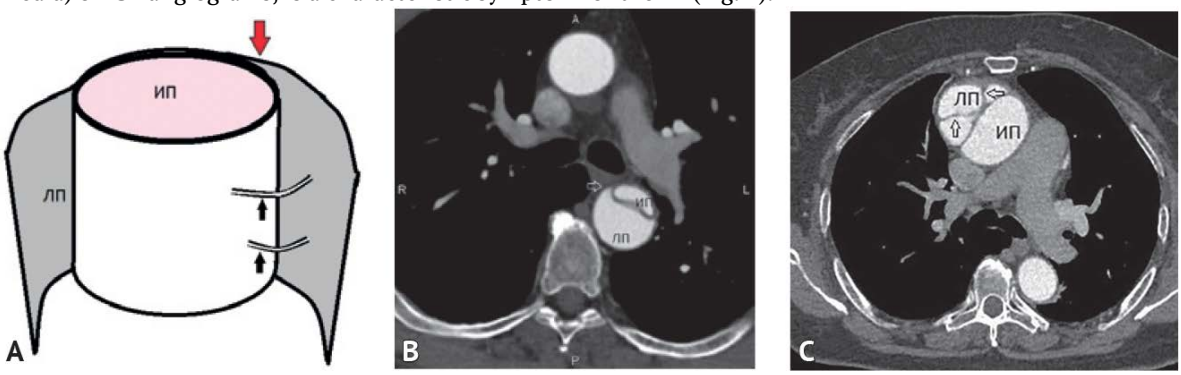

Fig. 2. The beak sign is an acute angle between the outer wall and the exfoliated intima (red arrow in diagram A, arrow in fig. B). The cobweb sign is linear structures in the false lumen (black arrows in diagram A, arrow in Fig. B). ИП — true lumen; ЛП — false lumen)

The cobweb sign is the presence of filamentous linear structures in the contrasted false lumen, which are collagen and fibrin "bridges" between the aortic lumens.

In the studied group, the beak sign was detected in 98 cases (85%); among those, 52 patients with type I AD, 15 patients with type II AD, 31 patient with type III AD. This symptom occurred in 68 out of 71 (95.8%) patients with acute AD stage, in 15 out of 18 (83.3%) patients with subacute AD stage, in 15 out of 26 (57.7%) patients with chronic AD stage (Table 6).

Table 6

The occurrence of the beak sign in the studied group

Stages of aortic dissection	Number of cases	The beak sign		*p*
		NO	YES	
Acute (1)	**71**	3 (4.2%)	68 (95.8%)	$p_{1,2}$=**0.060** $p_{1,3}$<**0.001**
Subacute (2)	**18**	3 (16.7%)	15 (83.3%)	$p_{2,3}$=**0.0726**
Chronic (3)	**26**	11 (42.3%)	15 (57.7%)	$p_{1+2,3}$<**0.001**
Total	115	17	98	

Notes: $p_{1,2}$ — significance level for the beak sign in the group with acute and subacute stages of AD; $p_{1,3}$ — for the groups with acute and chronic AD; $p_{2,3}$ — for the groups with subacute and chronic stages of AD; $p_{1+2,3}$ — for the acute AD group combined with subacute AD group and chronic AD group

Analysis of the symptom's frequency of occurrence, presented in Table 6, showed that it occurred in 85% of patients with AD, however, it was determined much more often in patients with acute and subacute AD stages than in patients with chronic AD stage (p<0.001).

The cobweb sign was detected in 42 patients (36.5%); among those, 26 patients with type I AD, 7 patients with type II AD, 9 patients with type III AD. This symptom occurred in 35 (49%) patients with acute AD stage, in 2 (11%) patients with subacute AD stage, in 5 (19%) patients with chronic AD stage (Table 7). The cobweb sign was found in a third of patients with AD, however, it was statistically significantly more common in patients with acute and subacute AD stages (p<0.05).

Table 7

The occurrence of the cobweb sign in the studied group

Stages of aortic dissection	Number of cases	Type of dissection		*p*
		NO	YES	
Acute (1)	**71**	36 (50.7%)	35 (49.3%)	$p_{1,2}$=**0.0033** $p_{1,3}$=**0.0077**
Subacute (2)	**18**	16 (88.9%)	2(11.1%)	$p_{2,3}$=0.469
Chronic (3)	**26**	21 (80.8%)	5 (19.2%)	$p_{1+2,3}$=**0.0003**
Total	115	73	42	

Notes: $p_{1,2}$ — significance level when comparing the frequency of observation of the cobweb sign in the group with acute and subacute stages of aortic dissection; $p_{1,3}$ — for groups with acute and chronic aortic dissection; p2,3 — for groups with subacute and chronic aortic dissection; $p_{1+2,3}$ — for the group of acute AD and subacute AD group combined with chronic AD group

THE ORIGINATING OF VISCERAL BRANCHES AND ILIAC ARTERIES

To assess the variations for the originating of the visceral branches of the aorta and iliac arteries, we analyzed only cases with the dissection of the abdominal aorta (n=96).

The celiac trunk originated from the true lumen in 90 (93.8%) cases, from the false one in 3 (3.1%) cases. In 3 other cases, the dissection involved the celiac trunk, which made it difficult to assess the originating variation.

The superior mesenteric artery originated from the true lumen in 92 (96%) cases, from the false one in 2 (2%) cases. In 2 other cases, the assessment of the originating was difficult due to the transition of the dissection to the artery.

The renal arteries on the right originated from the TL in 68 (70.8%) cases, from the FL — in 28 (29.2%) cases. On the left, the renal arteries originated from the TL in 52 (54.2%) cases, from the FL in 44 (45.8%) cases.

Transition of the dissection to the common iliac arteries (CIA) took place in 84 cases. At the same time, both CIA were dissected in 47 patients (56%). The transition of the dissection to the right CIA was noted in 10 (12%) patients, to the left CIA — in 27 (32%) patients.

DISCUSSION

Aortic dissection is one of the most dangerous and unpredictable diseases, and in most cases requires surgical treatment. To date, CT is the most informative method of non-invasive diagnosis of AD. According to the International Registry of Acute Aortic Dissections (IRAD), CT is the first diagnostic test performed in about 70% of patients with suspected acute aortic syndromes [18]. The method allows surgeons to identify the type of lesion with high accuracy and answer a number of critical questions. One of these tasks is the differentiating the true lumen from the false lumen in case of AD. Further assessment of the state of each of the lumens makes it possible to identify the level and obvious causes of impaired blood flow in the aorta and its main branches, which is especially important in acute dissection. Evaluation of variations for the originating of the lateral aortic branches (from the TL or FL) before surgery allows surgeons to determine the risk of intra- and postoperative ischemia of the internal organs, as well as to choose ways to minimize such dangerous complications.

Detailed marking of the aortic lumens in AD is necessary for correct planning of the level of implantation of vascular endoprostheses or uncovered stents in TL, as well as selection of their diameter [19].

The study presented a number of CT features that can help in the differentiating the true lumen from the false lumen of the aorta in case of its dissection. The most common and absolutely specific sign of FL was its size, which prevailed over TL size in all the cases, regardless of the type and stage of AD. Similar results were obtained in the study by M.A. Le Page et al., who compared CT data of 51 patients with AD [14]. The analysis of the false lumen/true lumen ratio, carried out in our work, showed that pronounced (more than 75%) compression of the TL is statistically more common in patients with acute and subacute AD stages.

Extended analysis of CT data also showed a certain regularity in the location of the aortic lumens at different levels. At the level of the ascending aorta, the FL was most often located along the right and anterior walls (94.5%). At the level of the descending thoracic aorta, the FL was more often located along the posterior and left walls (84%). In the abdominal aorta, the FL was more often located along the posterior and left aortic walls (70%). This pattern can be of practical use both at the stage of diagnosis and during surgery. One example of

the application of the obtained results is the correct location of the trigger zone during aortic CT to track the contrast agent in the TL. Such a solution will reduce the number of studies with low visualization quality associated with untimely start of the scan.

Calcification of the aortic wall not affected by dissection refers to fairly characteristic signs of TL. This theory is confirmed by our study which showed that calcification of the aortic wall was most often localized on the intact wall of the TL (more than 90%). However, this symptom is not found in all patients with AD, but mainly in the group older than 50 years. Thus, this feature can be considered highly specific for the TL, but its occurrence is limited.

Thrombosis of one of the aortic lumens in our study was detected in more than half of the cases and significantly predominated in the FL. At the same time, TL thrombosis occurred only in the acute and subacute AD stages (13% and 1.5%). In the patients with chronic AD stage, this symptom was not detected. From this it follows that TL thrombosis is characteristic of the acute AD stage, but occurs rarely, so its diagnostic value is limited. A similar conclusion can also be made about the cobweb sign which was statistically more common in the group with acute and subacute AD stages.

The beak sign is a characteristic feature of the FL, and it was found in the majority of patients with AD. The results of statistical processing showed its high diagnostic value in the acute AD stage.

The originating of the celiac trunk and superior mesenteric artery from the TL occurred in more than 90% of cases, which indicates their high diagnostic significance in the differentiation of the lumens. Less valuable were the data for the renal and iliac arteries.

The study of the regularities in the location of the aortic lumens became the basis for the creation of a number of programs for the automatic diagnosis of AD, including those based on artificial intelligence [19–24]. In the work of D. Lewis et al. from Stanford University, the results of the application of a program based on the method of machine learning, in particular CNN (Convolutional Neural Network), for the identification of type III AD and marking lumens are presented [20]. The results of this work showed a high accuracy of AD diagnosing, they correlated well with manual measurements. The value of such programs also lies in the possibility of obtaining quantitative and morphological parameters of the aorta, which is necessary for assessing treatment results and further monitoring.

CONCLUSION

Computed tomography is reasonably considered a highly informative method for diagnosing aortic dissection. The occurrence and value of diagnostic features studied in the work will allow, with a high degree of probability, to perform a quick and error-free differentiation of the true lumen from the false lumen of the aorta. The results obtained in conjunction with clinical and anamnestic data can also be useful in clarifying the stage of aortic dissection.

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