Anatomical Variations And Anomalies Of Internal Thoracic Artery Using Transthoracic Color Doppler Ultrasonography

INTERNAL THORACIC ARTERY ULTRASOUND ANATOMY

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***Abstract*—The objective of the study was to assess the anatomical variations and anomalies of ITA using transthoracic CDUSG.**

Methods. The study group included 135 consecutive patients who underwent CABG surgery with cardiopulmonary bypass. The mean age of the patients was 53.0±7.6 years. Fifty-two (38.5%) of these patients had a history of myocardial infarction. All patients had a multivessel coronary artery disease with a hemodynamically significant (>75%) proximal stenosis of the left anterior descending coronary artery. Transthoracic color Doppler ultrasonography was performed in all patients before surgery. Both ITAs were visualized from their origin to bifurcation to assess their anatomical variations and anomalies. Two-dimensional images and pulsed Doppler signals were obtained using a combined intercostal and supraclavicular approach. The following Doppler parameters were measured: a lumen diameter, a mean linear flow velocity, a flow volume, a pulsatory and resistance indexes.

Results. Doppler spectrum of a normal flow in the ITA is characterized by variability. The anatomical type of ITA bifurcation has a significant impact on a pulsatory index and especially on a resistant index but does not affect the flow velocities and ITA diameter. The following anatomical anomalies were diagnosed: duplication (3.7%), kinking (2.2%), hypoplasia (1.5%), hyperplasia (1.5%) and aneurisms (0.7%).

Conclusion. The incidence of ITA anomalies in the group of CABG candidates is 9.6% and 5.2% of the cases are hemodynamically significant. Therefore, color Doppler ultrasonography should be performed in patients before CABG.

Keywords— internal thoracic artery, anatomy, anomalies, ultrasonography

INTRODUCTION

With a widespread application of internal thoracic artery (ITA) grafts in coronary surgery the long-term results of coronary artery bypass grafting (CABG) are significantly improved due to the fact that ITA patency significantly exceeds the autovenous one [1-3]. However, a problem of an early occlusion of grafts arose due to its bloodflow and anatomical variability. Despite this fact, in the majority of clinics a decision on ITA adaptability for CABG is made directly during surgery. In some clinics a preoperative ITA angiography is used for these purposes. Very few surgeons prefer color Doppler ultrasonography (CDUSG) mainly due to a need for additional staff training.

Meanwhile, CDUSG meets all the requirements of clinicians, combining high specificity, sensitivity and predictive value. Being non-invasive, this technique doesn't have significant disadvantages restricting the use of invasive imaging techniques. To date CDUSG has been studied widely for the assessment of LITA graft patency [4-12]. In these studies, the ITA graft patency was assessed, but there are very few studies examining the morphology of ITA in situ supporting information about its adaptability for CABG.

The objective of the study was to assess the anatomical variations and anomalies of ITA using transthoracic CDUSG.

METHODS

The study was approved by Local Ethics Committee. Informed consent was obtained from all patients. The study group included 135 consecutive patients who underwent CABG surgery with cardiopulmonary bypass (CPB). The mean age of the patients was 53.0±7.6 years. Fifty-two (38.5%) of these patients had a history of myocardial infarction. Patients' characteristics are presented in Table 1. All the patients had a multivessel coronary artery disease with a hemodynamically significant (>75%) proximal stenosis of the left anterior descending coronary artery.

All the patients underwent transthoracic CDUSG before surgery using SSD-2200 ultrasound scanner (Aloka, Japan) with 7 MHz phased array linear transducer. Both ITAs were visualized from their origin to bifurcation to assess their anatomical variations and anomalies. Two-dimensional images and pulsed Doppler signals were obtained using a combined intercostal and supraclavicular approach. The angle of the ultrasound beam was corrected for the velocity measurements. The following Doppler parameters were measured: a lumen diameter, a mean linear flow velocity, a flow volume, a pulsatory and resistance indexes.The variables were presented in absolute values and percentages of the overall group quantity or mean and standard deviation. Statistical analysis was performed in MedCalc v. 17.2 using Mann-Whitney test.

Results and discussion

Normal ITA in situ can be visualized along the whole length as a tubular structure divided by ribs shadows (fig. 1). One or two (which is more rarely) internal thoracic veins (fig. 2) go with the artery. Usually it is possible to visualize relatively large ITA lateral branches, among which the first anterior intercostal artery has the largest diameter (fig. 3). The presence of large anterior intercostal branches can cause postoperative coronary-intercostal steal syndrome due to dumping of significant amount of blood through these branches. Therefore, their presence should be considered when planning the surgery.

In the absence of anatomical anomalies, each ITA has two terminal branches: the musculophrenic and superior epigastric artery, which may take a variable part in the formation of the ITA bifurcation. Doppler spectrum of normal flow in the ITA is characterized by variability dependent on anatomical variants of its bifurcation. Fig. 4 illustrates the anatomical variants of ITA bifurcation and their effect on a flow spectrum in the trunk of ITA. Musculophrenic artery is a typical muscular vessel and almost the only source of blood supply of massive ipsilateral cupula of the diaphragm. If it is the main branch of the distal ITA flow pattern has the characteristics typical of the peripheral arteries: biphasis, a relatively wide spectrum, a high diastolic component and a low resistance index (fig 4, A).

A superior epigastric artery is a typical elastic vessel that anastomoses with an inferior epigastric artery – the most proximal branch of the external iliac artery. Blood pressure in the superior epigastric artery during the late systole and diastole is very high for such a small vessel caliber. Therefore, if it forms the main branch of the ITA bifurcation its flow spectrum has the characteristic of a magistral type artery flow: three-phase relatively narrow spectral band, a low diastolic component and a high index of resistivity. It also could have the rapid decrease in the systolic peak flow, the retrograde waves or almost no flow during diastole (Fig. 4, B).

The bloodflow velocity parameters in different ITA distal branches formation are presented in table 2. The anatomical type of ITA bifurcation has a significant impact on the pulsatory and especially the resistant index but does not affect the flow velocities and ITA diameter. This fact is important because traditionally the suitability of ITA for CABG is based on its flow volume.

I. Anatomical anomalies of ITA in patients with CAD

The anatomical anomalies in each patient can influence the surgical strategy. A few number of papers refers to this fact [5]. Totally 13 (9.6%) cases of anomaly were revealed in our group of 135 patients.

ITA duplication revealed by CDUSG and verified angiographically is shown at fig. 5. Two lumens with bloodflow in both of them are visualized; their diameter is 2.5 and 2.3 mm respectively. One of ITA is located superficially to fascia endothoracica and the other one is below it. The color Doppler mode allows making sure that both of vessels are arteries, not an artery and a vein. In both arteries the typical bloodflow pattern was registered by pulsed Doppler mode. This also can exclude the artifact of fibrous structure ultrasound beam reflection.

The ITA duplication is the most frequent anomaly. In our group of patients ITA duplication was detected in 5 (3.7%) cases. In all the cases both of ITAs were visualized over the whole longitude and had a relatively equal lumen diameter (fig. 6).

The distal (epigastric and musculophrenic) branches can origin from one of duplicated ITA or from both of them (fig. 7). The last case should be considered as an extremely high origin of ITA terminal branches. In 3 cases (2.2%) of ITA duplication both branches originated from epifascial ITA.

II. **ITA kinking** was diagnosed as C-shaped or S-shaped in three (2.2%) patients of our group (fig. 8-9). All of them had high-grade uncontrolled arterial hypertension. The kinking can be hemodynamically significant or not. The first variant is characterized by a high linear velocity and a turbulence of bloodflow at the level of curvature that usually happens in right or sharp angle of kinking.

In **ITA hyperplasia** its lumen diameter exceeds 3.1 mm (fig. 10), and in **hypoplasia** it becomes less than 1.9 mm (fig. 11) during nifedipine test [13]. In our group of patients both anomalies occurred in two cases (1.5%). In one of them hyperplasia was associated with the aortic coarctation. It is known that this congenital defect leads to the development of collaterals between segments before and after the narrowing (usually they are ITA and intercostal arteries). Such cases of ITA hyperplasia seem not to be a separated anomaly. On the other hand, congenital anomalies of great vessels may have a systemic nature, and other elastic arteries can also be the target lesion. In the similar manner ITA hypoplasia can be a part of middle aortic syndrome [14]. In the case presented at fig. 12 the narrowed aortic segment

was corrected in infancy using synthetic prosthesis, however hyperplastic collaterals remained until middle age.

Taking into account a high vasospastic potential of CAD patients the diagnosis of ITA hypoplasia can be made only using vasodilatator tests (nifedipine in our study).

In our group of patients only one (0.7%) case of **ITA aneurism** was detected. Nevertheless, the artery was successfully used as a coronary graft and was patent after a year of follow-up (fig. 13).

The incidence of ITA anatomical anomalies is shown in table 3.

Discussion

This study demonstrates the available ways to increase the quality of non-invasive diagnosis of ITA anomalies in candidates for CABG. Ultrasonographic visualization of ITA throughout its whole length and its main branches is possible in all patients without any specific preparation. The variants of normal ITA topography are described including the presence of one or two internal thoracic veins as well as large intercostal branches which should be clipped during ITA harvesting to prevent a mammary-intercostal steal [15-17].

Using triplex Doppler mode we revealed that spectral characteristics of normal ITA bloodflow depend on its bifurcation type. If the main ITA distal branch is a musculophrenic artery then the ITA bloodflow has a ‘peripheral’ pattern with a low resistive index. If the main ITA distal branch is a superior epigastric artery then the ITA bloodflow has a ‘magistral’ pattern with a high resistive index similar to the one of the subclavian artery. In both variants the basic ITA hemodynamic characteristics such as the lumen diameter, the mean linear velocity or the flow volume were the same. Therefore, despite the fact that in our group of patients the ‘magistral’ type of ITA bloodflow prevails, the both anatomical variants should be considered as the normal ones.

The overall amount of 13 (9.6%) cases of ITA anatomical anomalies in the group of 135 patients were described, and 5.2% of them were hemodynamically significant. The most frequent anomaly was ITA duplication.

The detection of any anatomical anomaly can affect the surgical strategy. For example, hemodynamically significant kinking can be eliminated by ITA skeletonizing. ITA duplication or a very proximal bifurcation allows performing a dual-vessel grafting. Hyperplasia or hypoplasia of ITA can make this artery unsuitable for CABG.

Conclusion

The incidence of ITA anomalies in the group of CABG candidates is 9.6% and 5.2% of the cases are hemodynamically significant. Therefore, color Doppler ultrasonography should be performed in patients before CABG.

a. Table 1 – Clinical characteristics of the studied patients

Characteristic	Value
Male gender	97 (71.8%)
Mean age (years)	53.0±7.6
Myocardial infarction in anamnesis	52 (38.5%)
Arterial hypertension	89 (65.9%)
Diabetes mellitus	27 (20%)
Dyslipidemia	113 (83.7%)
Stroke in anamnesis	13 (9.6%)
Peripheral atherosclerosis	13 (9.6%)
Atrial fibrillation	18 (13.3%)
LV ejection fraction by Simpson biplane (%)	41.2±6.4

x. Table 2 – Bloodflow characteristics by CDUSDG in different types of ITA bifurcation

y. **Parameter**	z. **Magistral type (n=58)**	aa. **Peripheral type (n=77)**	bb. **P**
MLV (cm/s)	cc. 22.2±11.5	dd. 23.7±9.0	ee. p>0.1
FV (ml/min)	ff. 52.5±26	gg. 58.0±30.3	hh. p>0.1
PI	ii. 1.951±0.822	jj. 2.040±0.888	kk. p<0.01
RI	ll. 1.132±0.3	mm. 0.908±0.101	nn. p<0.01
ITA diameter (mm)	oo. 2.3±0.5	pp. 2.3±0.4	qq. p>0.1
MPA diameter (mm)	rr. 1.2±0.2	ss. 2.0±0.4	tt. p<0.01
SEA diameter (mm)	uu. 2±0.3	vv. 1.2±0.2	ww. p<0.01
MPA diameter / SEA diameter	xx. 1.750±0.337	yy. 0.609±0.022	zz. p<0.01

Comment. *MV: mean linear velocity; FV: flow volume; PI: pulsatory index; RI: resistive index.*

aaa. Table 3 – The incidence of ITA anomalies in CAD patients

bb. **Anomaly**	cc. **Overall**	dd. **Hemodynamically significant**
eee. Duplication	fff. 5 (3.7%)	ggg. 0 (0%)
hhh. Kinking	iii. 3 (2.2%)	jjj. 3 (2.2%)
kkk. Hypoplasia	lll. 2 (1.5%)	mm. 2 (1.5%)
nn. Hyperplasia	oo. 2 (1.5%)	pp. 2 (1.5%)
qqq. Aneurisms	rrr. 1 (0.7%)	sss. 0 (0%)
ttt. Total	uuu. 13 (9.6%)	vvv. 7 (5.2%)

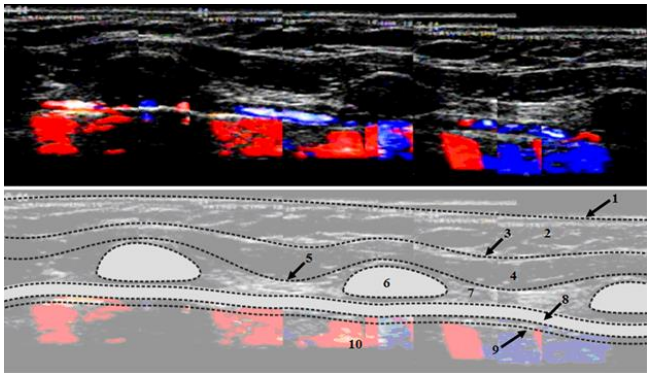

Fig. 1. *ITA topography along the whole length by color Doppler ultrasonography: 1 – skin surface; 2 – subcutaneous fatty tissue; 3 – superficial leaf of pectoral fascia; 4 – pectoral muscles; 5 – deep leaf of pectoral fascia; 6 – rib; 7 – intercostal muscles; 8 – lumen of ITA; 9 – fascia endothoracica; 10 – thoracic cavity*

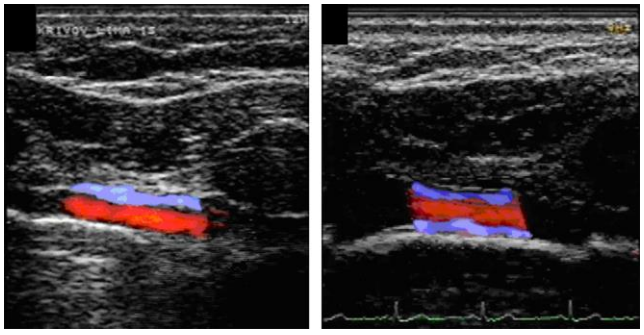

Fig. 2. *Anatomical variants of one or two internal thoracic veins*

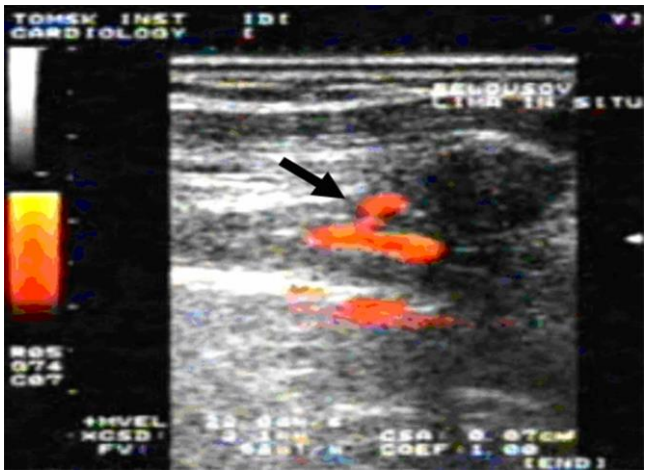

Fig. 3. *The first anterior intercostal artery origin (arrow)*

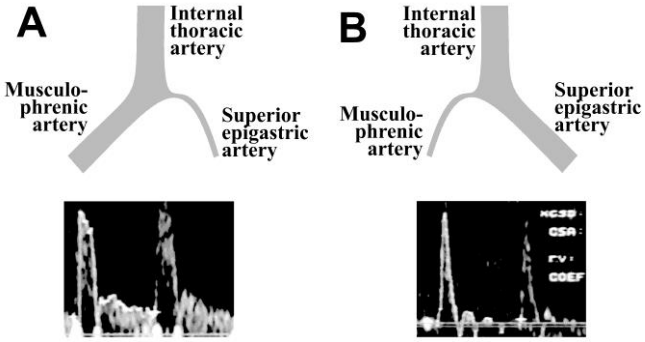

Fig. 4. *Anatomical variants of ITA terminal branches formed mainly by musculophrenic (A) or superior epigastric (B) artery and corresponding ITA bloodflow spectra*

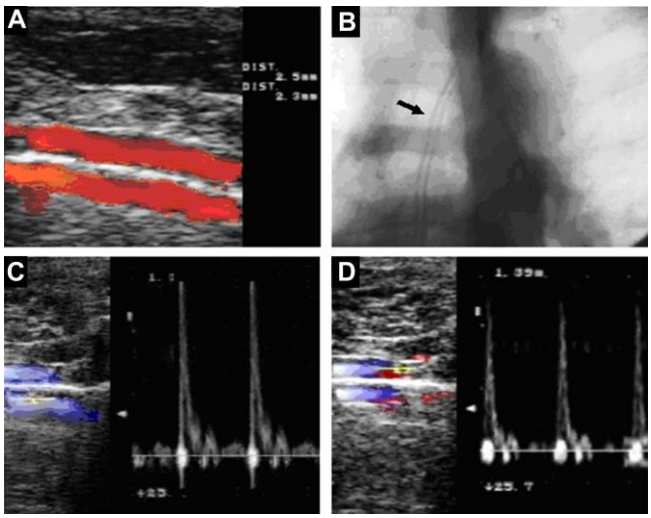

Fig. 5. *ITA duplication: A – measuring of lumen diameters in color Doppler mode; B – semiselective angiography of both ITAs (arrow) in left anterior oblique view; C, D – bloodflow spectrum of superficial (C) and profound (D) ITA in pulsed Doppler mode*

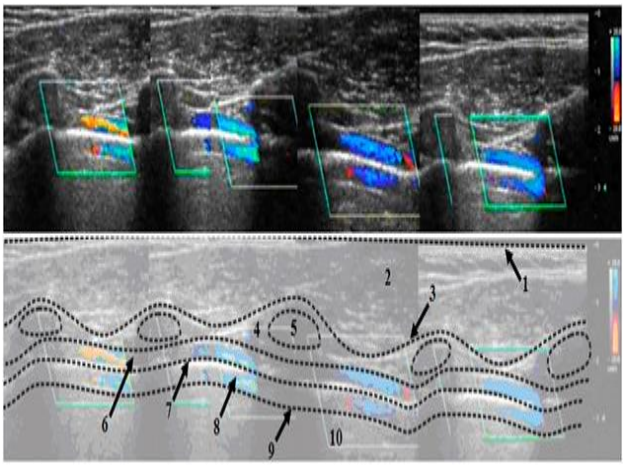

Fig. 6. *ITA duplication topography along the whole length by color Doppler ultrasonography: 1 – skin; 2 – subcutaneous fatty tissue and pectoral muscles; 3 – deep leaf of pectoral fascia; 4 – intercostal muscles; 5 – rib; 6 – epifascial ITA; 7 – fascia endothoracica; 8 – subfascial ITA; 9 – parietal pleura; 10 – thoracic cavity*

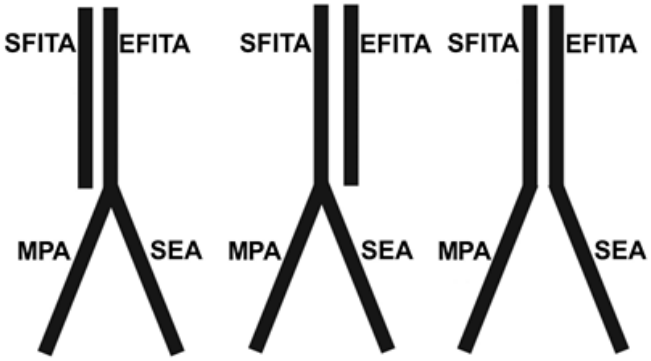

Fig. 7. *Variants of duplicated ITA terminal branches: SFITA: subfascial internal thoracic artery; EFITA: epifascial internal thoracic artery; MPA: musculophrenic artery; SEA: superior epigastric artery*

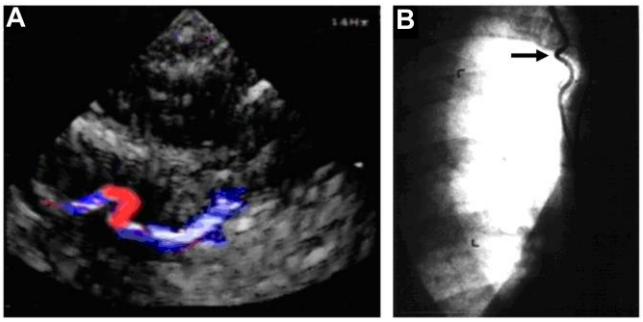

Fig. 8 *C-shaped ITA kinking: A – ultrasonography in color Doppler mode; B – selective ITA angiography (curved segment is marked by arrow)*

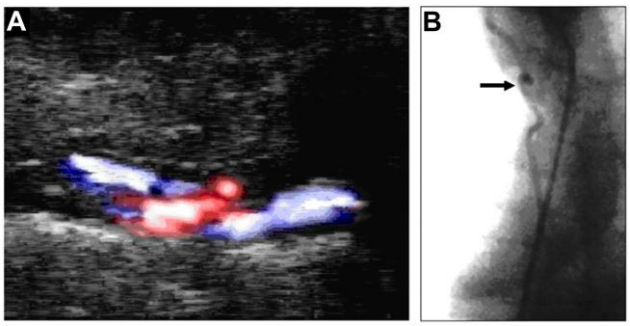

Fig. 9. *S-shaped kinking: A – ultrasonography in color Doppler mode; B – selective ITA angiography (curved segment is marked by arrow)*

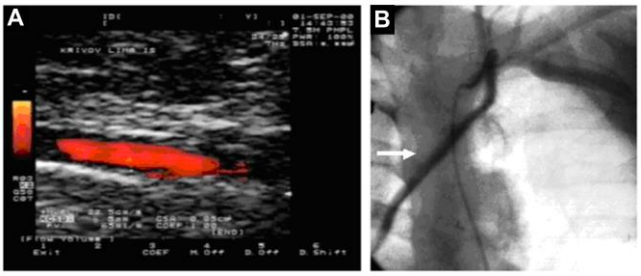

Fig. 10. *ITA hyperplasia: A – ITA ultrasonogram in color doppler mode (lumen diameter is 6.5 mm); B – semiselective ITA angiography in left anterior oblique view: ITA is indicated by arrow. For reference the diameter of angiographic catheter is 2.2 mm*

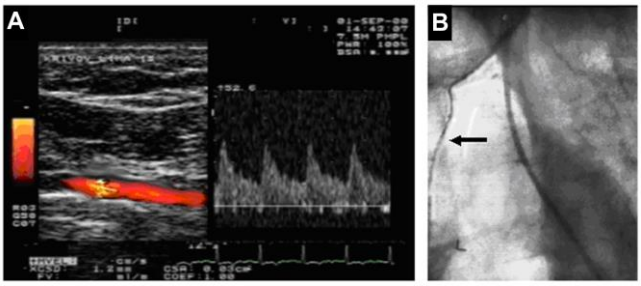

Fig. 11. *ITA hypoplasia: ITA ultrasonogram in color doppler mode (lumen diameter is 1.2 mm, and flow spectrum is similar to collateral bloodflow type); B – semiselective ITA angiography in left anterior oblique view: ITA is indicated by arrow. For reference the diameter of angiographic catheter is 2.2 mm*

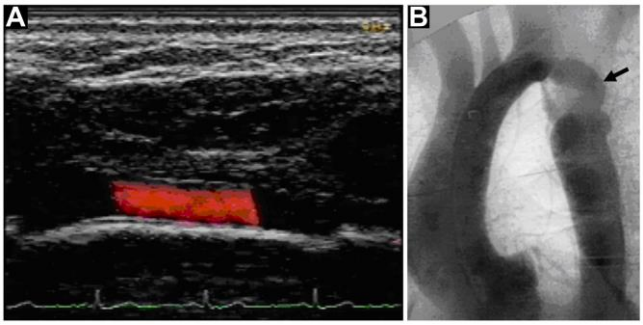

Fig. 12. *ITA hyperplasia associated with aortic coarctation corrected with synthetic prostheses plastic: A – ITA ultrasonogram in color doppler mode; B – thoracic aortography in left anterior oblique view (prosthesis is indicated by arrow)*

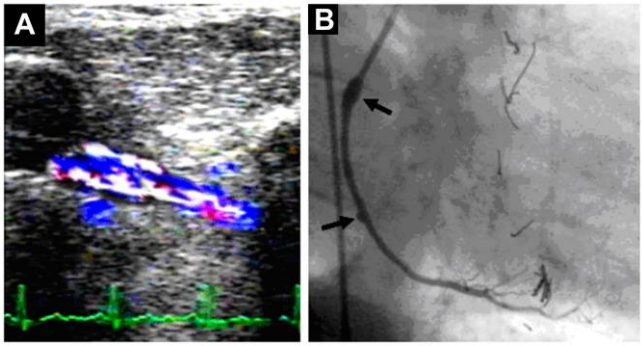

Fig. 13. *Multiple ITA aneurisms: A – in ITA ultrasonogram in color doppler mode the luminal diameter thickness and bloodflow turbulence are occured; B – selective angiography of mammarocoronary bypass graft (aneurisms are indicated by arrows)*

References

[1] Taggart DP, Altman DG, Gray AM, Lees B, Nugara F, Yu LM, et al. Randomized trial to compare bilateral vs. single internal mammary coronary artery bypass grafting: 1-year results of the Arterial Revascularisation Trial (ART). Eur Heart J. 2010;31:2470–2481.

[2] Goldman S, Zadina K, Moritz T, Ovitt T, Sethi G, Copeland JG, et al. Long-term patency of saphenous vein and left internal mammary artery grafts after coronary artery bypass surgery: results from a Department of Veterans Affairs Cooperative Study. J Am Coll Cardiol. 2004;44:2149–2156.

[3] Cameron A, Davis KB, Green G, Schaff HV. Coronary bypass surgery with internal-thoracic-artery grafts–effects on survival over a 15-year period. N Engl J Med. 1996;334:216–219.

[4] Kolesov VI, Kolesov EV. Twenty years' results with internal thoracic artery-coronary artery anastomosis. J Thorac Cardiovasc Surg. 1991;101(2):360-361.

[5] Kolesov E.V. Preoperative checking of IMA(s): to do or not to do? // Eur. J. Cardiothorac. Surg. – 2000. – Vol. 17. – P. 190–191.

[6] Rombaut E, Vantrimpont P, Gurné O, Chenu P, Schroeder E, Buche M, et al. Noninvasive functional assessment of left internal mammary artery grafts by transcutaneous Doppler echocardiography. J Am Soc Echocardiogr 1998; 11: 403-8.

[7] Nikodemska I, De Bono DP, Spyt TJ, Wiechowski S, Nikodemski T. Preoperative and early postoperative assessment of the internal thoracic artery by transcutaneous duplex ultrasound in coronary artery bypass grafting. Int J Cardiol 1998; 66: 39-44.

[8] Pezzano A, Fusco R, Child M, Riccobono S, Milazzo A, Recalcati F, et al. Assessment of left internal mammary artery grafts using dipyridamole Doppler echocardiography. Am J Cardiol 1997; 80: 1603-6.

[9] Canver CC, Ricotta JJ, Bhayana JN, Fiedler RC, Mentzer RM Jr. Use of duplex imaging to assess suitability of the internal mammary artery for coronary artery surgery. J Vasc Surg 1991; 13: 294-301.

[10] Meyer GP, Laudenberg B, Hausmann D, Mügge A, Cremer J, Hornig B, et al. Transthoracic Doppler validation in mammary artery grafts after minimal invasive direct coronary artery bypass operation. J Am Soc Echocardiogr 2004; 17: 954-61.

[11] Takagi T, Yoshikawa J, Yoshida K, Akasaka T. Noninvasive assesment of left internal mammary artery graft patency using duplex Doppler echocardiography from supraclavicular fossa. J Am Coll Cardiol 1993; 22: 1647-52.

[12] Yay K, Boysan E, Ünal EU, Çicekçioğlu F, Tola M, Kocabeyoğlu S, Başar V, Katırcıoğlu F. Diagnostic accuracy of Doppler ultrasonography for assessment of internal thoracic artery graft patency. Anadolu Kardiyol Derg 2014; 14: 286-91

[13] Tepliakov AT, Vecherskiĭ Iulu, Mamchur SE, Dzhavadova GK, Nemik BM. Postoperative spasm of mammary-coronary grafts and possibilities of its correction by dihydropyridine calcium antagonists nifedipine and amlodipine. Kardiologiia. 2002;42(10):9-14. [Article in Russian]

[14] Delis KT, Gloviczki P. Middle aortic syndrome: from presentation to contemporary open surgical and endovascular treatment. Perspect Vasc Surg Endovasc Ther. 2005 Sep;17(3):187-203.

[15] Abhyankar A.D., Mitchell A.S., Bernstein L. Lack of evidence for improvement in internal mammary graft flow by occlusion of side branch // Cathet. Cardiovasc. Diagn. – 1997. – Vol. 42. – P. 291–293.

[16] Gaudino M., Serricchio M., Tondi P. et al. Do internal mammary artery side-branches have the potential for haemodynamically significant flow steal? // Eur. J. Cardiothorac. Surg. – 1999. – Vol. 15. – P. 251–254.

[17] Missault L., Taeymans Y., Caes F. et al. Transcatheter treatment of angina after coronary surgery due to concomitant internal mammary steal and right coronary artery stenosis: a need for staging // Cathet. Cardiovasc. Diagn. – 1994. – Vol. 32. – P. 283–285.