ARTICLE — CLINICAL STUDY

The internal mammary artery bypass - the principles of preoperative and postoperative diagnosis using colour-duplex ultrasound

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Abstract

Background: **The aim of the study was the assessment of functional characteristics of the left internal mammary artery (LIMA) bypass in patients after coronary artery bypass grafting (CABG) in comparison with the native LIMA using colour-duplex ultrasound as the non-invasive diagnostic method.**
Methods: **We examined 303 patients after myocardial revascularization with the internal mammary artery bypass using the Hewllett Packard 2500, 5500 ultrasound units. Using the 7.5 MHz linear transducer we detected the LIMA from the left supraclavicular approach. We assessed the peak systolic velocity (PSV — cm/s), peak diastolic velocity (PDV — cm/s), end-diastolic velocity (EDV — cm/s) and we calculated the peak systolic/peak diastolic velocity ratio (SDVR) and resistance index RI (PSV-EDV/PSV). The obtained parameters were compared with the native LIMA flow characteristics of the 70 consecutive patients before CABG.**
Results: **We observed the transformation of internal mammary artery flow from the predominantly systolic high resistance type of the native LIMA, to the low resistance biphasic waveform after its use as a coronary artery graft. We detected a significant increase of diastolic flow velocities and a significant decrease of resistance and of the SDVR ratio. In dysfunctional grafts we found a decrease of diastolic flow and an increase of LIMA resistance and SDVR.**
Conclusion: **The colour-duplex ultrasound is a perspective non-invasive method for the postoperative follow-up of patients with the LIMA graft. It allows the assessment of the bypass flow characteristics, functional status and patency and it could contribute to the early diagnosis of bypass failure.** ***(Fig. 6, Tab. 4, Ref. 21.)***
Key words: duplex ultrasound, myocardial revasularization, CABG, LIMA, internal mammary artery graft.

The left internal mammary artery (LIMA), (a. mammaria interna = a. thoracica interna) is the conduit of choice for revascularization of coronary arteries.

Long-term postoperative follow-up has shown superior patency, reduced incidence of recurrent angina, and mainly the increased survival after using the LIMA compared with saphenous vein grafts (1). The „gold standard" diagnostic method for assessment of the postoperative LIMA graft patency is angiography. However, angiography is limited by its invasive nature, its cost and availability.

Colour-duplex ultrasound is non-invasive, repeatable, available, and less expensive way of long-term follow-up of patients with recurrence of angina symptoms after CABG.

Therefore in recent years there is a growing evidence of the non-invasive transthoracic duplex ultrasound imaging for preoperative assessment of the native LIMA as well as for the postoperative detection of the LIMA graft patency (2—11).

Also our working group has started to practise this new diagnostic method in 1998 as the first department in Slovak Republic. Our first experiences were presented at the IV. Congress of The Slovak Society of Cardiology in 1999 in Košice (12).

The objectives of our study was to evaluate the non-invasive colour-duplex ultrasound technique in assessment of functional

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Tab. 1. The type of myocardial revascularization procedure.

LIMA - RIA / LIMA - RD	291/12
CAGB - ECC	251
OPCAB	39
MIDCAB	13

LIMA — left internal mammary artery, RIA — ramus interventricualris anterior, RD — ramus diagonalis, CABG — coronary artery bypass grafting, ECC — extra-corporal circulation, OPCAB — off pump coronary artery bypass, MIDCAB — minimally invasive direct coronary artery bypass

status of the LIMA before and after CABG and to observe flow changes between patent and dysfunction internal mammary artery bypass.

Subjects and methods

Between November 1998 and April 2001 we examined 303 patients with internal mammary artery bypass by transthoracic colour-duplex ultrasound technique. There were 193 men and 110 women, aged 43 to 76 (mean 61) years whose underwent coronary artery bypass grafting using the left internal mammary artery as a bypass conduit.

In 291 cases LIMA bridged LAD (left anterior descending coronary artery), in 12 patients it anastomosed the DB (diagonal branch). The 251 examination were performed after myocardial revasularization in extra corporal circulation (CABG-ECC — extra-corporal circulation), 39 patients underwent OPCAB (off pump coronary artery bypass) through the median sternotomy, 13 LIMA were examined after MIDCAB (minimally invasive direct coronary artery bypass) via the small thoracotomy (Tab. 1).

Duplex ultrasound: Ultrasound examination we performed using ultrasound units Hewlett Packard 2500 and 5500 equipped with a 7.5 MHz linear transducer. Transthoracic visualisation of the LIMA was accomplished in patients lay in a relaxed supine position from the left supraclavicular approach. With two-dimensional color flow mapping we identified position of the proximal LIMA 1—2 cm after its origin from the left subclavian artery. Using the pulsed Doppler method and 2—3 mm sampling volume located within the vessel lumen we obtained intraluminal flow signal. Angle correction was applied for the velocity measurements. We measured following parameters: the peak systolic velocity (PSV — cm/s), the peak diastolic velocity (PDV — cm/s) and the end-diastolic velocity (EDV — cm/s). Than we calculated peak systolic to peak diastolic velocity ratio SDVR (PSV/PDV) and the resistance index: RI=(PSV-EDV)/PSV.

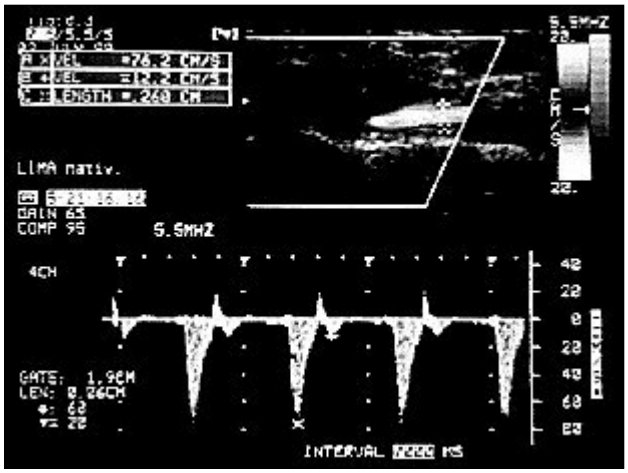

Fig. 1. Native LIMA.

The same parameters we obtained in native LIMA of 70 consecutive patients before CABG. The native LIMA was visualised from the left parasternal window of the second intercostal space.

Angiography: Selective or semiselective left internal mammary artery bypass angiography was performed in the subgroup of patients at the end of routine left heart catheterization (Coronoscop, Siemens). LIMA graft was imaged by LAO 90 (left anterior oblique) and RAO 30 (right anterior oblique) views. Quantitative analysis was performed with computerised digital system (Medis).

Tab. 2. The preoperative and postoperative LIMA flow characteristics.

	N	PSV (cm/s)	PDV (cm/s)	EDV (cm/s)	SDVR	RI
LIMA native	70	83,39 ± 20,49	17,42 ± 7,13	7,32 ± 3,83	5,37 ± 2,23	0,91 ± 0,04
Functional LIMA bypass	270	62,12 ± 22,03*	40,55 ± 15,87*	15,10 ± 7,27*	1,60 ± 0,42*	0,75 ± 0,09*
Dysfunctional LIMA bypass	11	57,52 ± 12,80	16,62 ± 3,63	9,68 ± 2,85	3,61 ± 1,06	0,82 ± 0,06

N — number of patients, PSV — peak systolic velocity, PDV — peak diastolic velocity, EDV — end-diastolic velocity, SDVR — peak systolic/peak diastolic velocity ratio, RI — resistance index * $p < 0.001$ VS.LIMA native

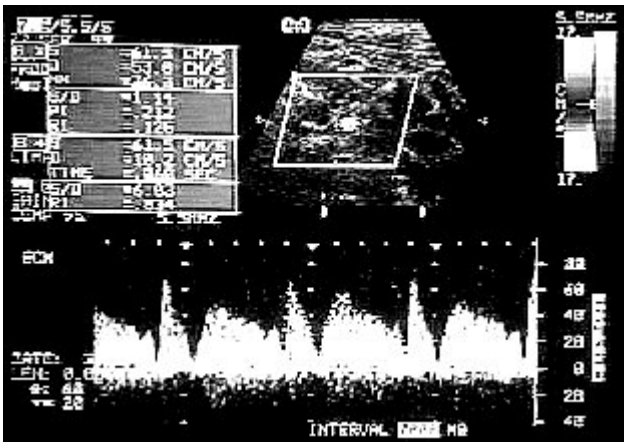

Fig. 2. Patent LIMA bypass.

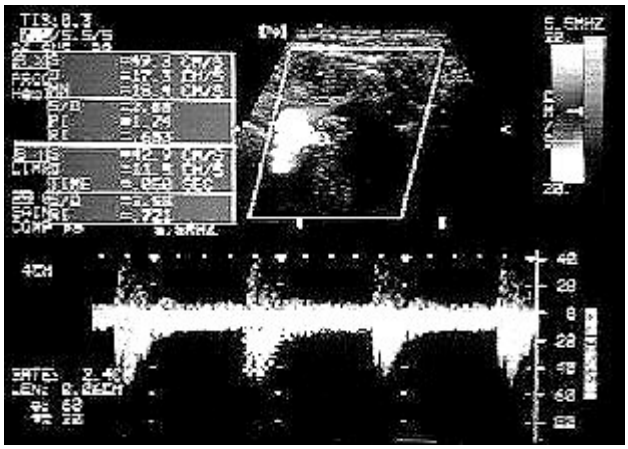

Fig. 3. Dysfunctional LIMA bypass — distal stenosis.

Statistical analysis: All data are present as mean±SD. LIMA and LIMA-LAD Doppler variables were evaluated by unpaired Student's *t*-test. Statistical significance „p" was calculated.

Results

Detection rate of LIMA: In all 70 patients we succeeded in good preoperative ultrasound visualisation of the left internal mammary artery, and we obtained all measured parameters. Postoperative images of the LIMA grafts were adequate in 287 of 303 patients (94.72 %).

LIMA preoperative: Blood flow in 70 native internal mammary arteries was dominant during systole, which is typical for the high resistance peripheral arteries. After the short-duration systolic phase with a large peak of antegrade flow, the short duration retrograde flow in early diastole and low velocity antegrade diastolic component in late diastole were followed (Fig. 1).

The values of the flow parameters were PSV: 83.39±20.49 cm/s, PDV: 17.42±7.13 cm/s, EDV: 7.32±3.83 cm/s, SDVR: 5.37±2.23, RI: 0.91±0.04.

Functional LIMA bypass: In 270 patients we obtained a biphasic pattern of blood flow corresponding to systole and diastole with the dominant flow during diastole. Both systolic and diastolic phases were antegrade. In early diastole the blood flow increased rapidly, than gradually decreased and fell rapidly in late diastole (Fig. 2). This is characteristic for the patent internal mammary artery bypass. Measured parameters were PSV: 62.13±22.03 cm/s, PDV: 40.56±15.87 cm/s, EDV: 15.10±7.27 cm/s, SDVR: 1.60±0.42, RI: 0.75±0.09.

Dysfunctional LIMA bypass: In 11 patients with occluded or severely stenosed LIMA graft proved by angiography, we recorded broadening of the spectral curve with dominance of the flow during systole. In all patients we detected decrease of PDV and EDV and increase of the SDVR and RI.

PSV: 57.52±12.80 cm/s, PDV: 16.62±3.63 cm/s, EDV: 9.68±2.85 cm/s, SDVR: 3.61±1.06, RI: 0.82±0.06 (Tab. 2).

In 8 patients with anastomotic LIMA-LAD stenosis we detected decrease of the diastolic flow velocities (Fig. 3). In 3 patients with proximal LIMA occlusion or stenosis there was the complete loss of the diastolic blood flow when we measured it before the place of occlusion.

In one patient five years after the myocardial revascularization we detected the rare finding of the antegrade systolic flow followed by substantial but the retrograde diastolic component. Arch aortography and selective coronary arteriography confirmed the diagnosis of coronary subclavian steal syndrome caused by the significant stenosis of the left subclavian artery.

In 3 cases the followed angiography did not confirmed the false positive ultrasound finding of LIMA bypass stenosis. In 2 cases the ultrasound result was false negative. However, angiography examination was performed just in the low number of patients.

Compared with the native LIMA, the functional LIMA bypass is typical by significant decrease of PSV and significant increase of PDV and EDV, which result in significant decrease of SDVR and RI ($p<0.001$) (Fig. 4, 5).

The summary of the ultrasound findings is in Table 3.

Tab. 3. Color-duplex ultrasound of LIMA bypass -- summary.

Patent LIMA bypass	270
Signif. stenosis/occlusion dist. LIMA	8
Signif. stenosis/occlusion prox. LIMA	3
Coronary - subclavial steal sy.	1
USG false posit.	3
USG false negat.	2
Not visualised	16
Total	303

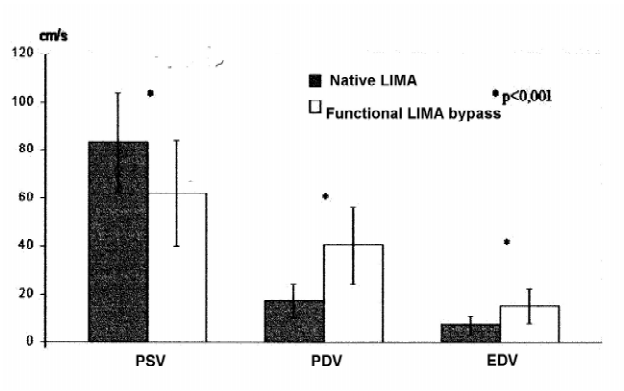

Fig. 4. LIMA flow velocities before and after CABG. PSV - maximal systolic velocity, PDV - maximal diastolic velocity, EDV - end-diastolic velocity. * p<0.001.

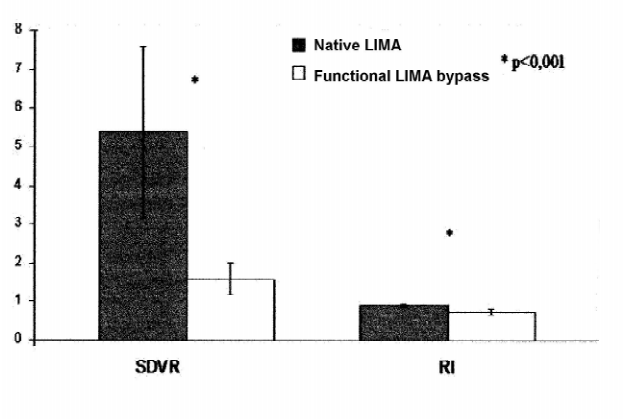

Fig. 5. Peak systolic to peak diastolic velocity ratio and resistance index of LIMA before and after CABG. SDVR — PSV/PDV — peak systolic/peak diastolic velocity ratio, RI — rezistenčný index. * p<0.001.

Discussion

In recent years there is a growing evidence of studies which bowed that colour-duplex ultrasound is a reliable diagnostic tool for the preoperative and postoperative assessment of the internal mammary artery and LIMA bypass (2—11). At the XXII. Congress of the European Society of Cardiology in Amsterdam in August 2000 and at the 5th World Congress of Echocardiography and Vascular Ultrasound in Seoul in May 2001 several presentations also dealt with ultrasound diagnosis of internal mammary artery bypass and coronary arteries (13—18).

The use of the internal mammary artery for myocardial revascularization has become a generally accepted standard and its popularity further increases in the era of mini-invasive coronary surgery. With increasing use of LIMA and expected increase of post-operative LIMA interventions, the duplex ultrasound method is gaining a prior necessity for its non-invasive character. It is connected with the high technical standard of ultrasound systems and the ability to detect the small vessels and their flow properties.

The success rate of visualisation of the LIMA following the bypass grafting has ranged from 81 % to 98 % (3, 4, 8, 9). Our results confirm this number (94.72 %).

However, it depends on many factors. Firstly, it is examination approach of LIMA. The LIMA graft can be imaged either from the left supraclavicular fossa (5, 6, 7, 9) or from the left parasternal window of the intercostal spaces (3, 4, 8). As the native course of the LIMA is more or less modified by the surgical procedure, we prefer the left supraclavicular fossa approach, which has the highest detection rate and it is the best site for repeated scans.

The success rate of visualisation is negatively influenced in the first postoperative period (ventilated patients at intensive care unit, postoperative oedema).

Preoperative examination

The blood flow in ungrafted internal mammary arteries occurs mainly during systole, which is typical for the flow in peripheral arteries.

Previously, we have described ultrasonic criteria of the internal mammary artery suitability for use during myocardial revascularization (19), and we took this method into a routine practise in our hospital. In the last 4 years we examined more than thousand native internal mammary arteries. The highest visualisation success rate of the native LIMA is from the left intercostal parasternal space. The LIMA suitable for CABG has the narrow, triphasic waveform, no visible morphologic changes and appropriate diameter of the lumen (2—4 mm). As contraindications we find LIMA diameter <2,0 mm, subclavian steal phenomenon and significant stenosis or occlusion of the vessel. However, this one is very rare and most often caused by the iatrogenic reason — clipping of the vessel during the previous cardiosurgery procedure (Tab. 4).

Postoperative examination

For the LIMA bypass a significant increase in diastolic flow velocity is typical.

Diastolic flow component is a marker of an increased blood flow into the low-resistance coronary arterial bed and indicating a patency and functional status of the LIMA graft.

The blood flow characteristics of **normal LIMA grafts** or moderate stenosis are similar to those in normal coronary circulation. The systolic component reflects the high intramyocardial

Tab. 4. Contraindications of LIMA suitability for CABG.

Diameter < 2 mm
Subclavial steal phenomenon
Stenosis/occlusion LIMA (rare)

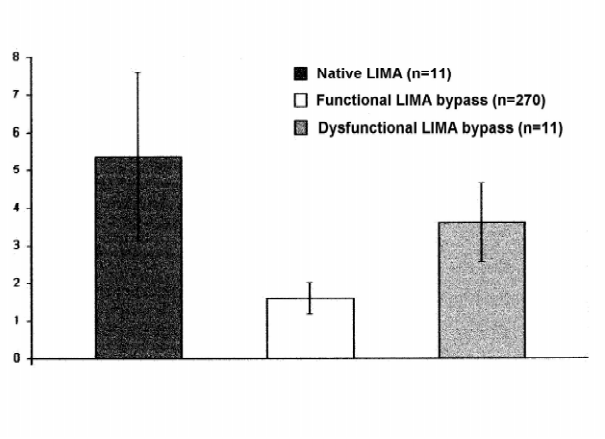

Fig. 6. SDVR — peak systolic to peak diastolic velocity ratio

resistance during myocardial compression in systole. Diastolic flow represents coronary perfusion throughout the LIMA graft during myocardial relaxation period, when intramyocardial resistance is low.

The predilection places of pathological changes of the LIMA graft are the anastomosis with coronary artery and proximal segment of the LIMA. *Proximally occluded LIMA graft* acts as a blind-ended tube. It has an absent flow or monophasic systolic flow with the loss of diastolic component when measured before the place of occlusion.

Typical for the critical *distal stenosis of the LIMA anastomosis* is the substantial decrease of diastolic flow component with the broadening of the Doppler curve, but not the complete loss of diastolic flow. It means that suspicions of graft dysfunction should be raised when there is an absent flow or significant reduction of diastolic blood flow and systolic dominance of a Doppler pattern.

A poor LAD target vessel quality, competitive flow from a partially occluded proximal LAD, residual LIMA side branches, and the contractility and viability of the perfused myocardium affect the Doppler flow values also (2, 8, 9).

All these factors could be associated with diminished of the LIMA-LAD diastolic flow.

The most of the authors use the ratio of systolic to diastolic peak velocits **SDVR (PSV/PDV)** or DSVR (PDV/PSV) as one of the predictors of the LIMA bypass functional status (4—9). SDVR is independent of the ultrasound beam angle, but it could be depends on the sampling site throughout the LIMA course (8, 20).

Our findings are similar to those of other investigators who used the supraclavicular approach (DSVR — Pezzano: 0.7±0.3, Rombaut: 0.7±0.3, Voudris: 0.72±0.23, SDVR — Nikodemska: 1.49±0.8) (5,6,7,9).

SDVR is significantly higher in preoperative examination compared to the postoperative patent LIMA bypass ($p<0.001$). We observed remarkable increase of SDVR of occluded or severely stenosed LIMA grafts compared to the patent LIMA conduits (Fig. 6). Apart from the assessment of LIMA bypass functional status in basal conditions, many authors prefer Doppler evaluation of LIMA graft patency during administration of a vasodilator (dipyridamole, adenosine), or after exercise stress test (5, 7, 8, 9).

With the development of the ultrasound technique there is a grooving number of studies deal with non-invasive Doppler diagnosis of coronary artery stenosis. It is based on the same principles as diagnosis of the internal mammary artery bypass (15, 16, 17, 21).

Finally we have to stress that the number of patients in our ultrasound study group which were examined also by angiography is less than 20 %. As the number of dysfunctional grafts is also not sufficient for statistical analysis, we did not evaluated the standard values and more detailed diagnostic criteria of the internal mammary artery grafts patency.

It should be the way of our future efforts to establish this method into a routine practise.

Conclusion

Colour-duplex ultrasound is a reliable, sensitive and rapid non-invasive method for the preoperative assessment of the internal mammary artery before CABG.

It is a perspective method for the long-term postoperative follow up patients with LIMA bypass.

Low resistance biphasic flow with dominant diastolic component is typical for patent LIMA grafts. Suspicion of the graft failure should be raised when there is an absent flow or a systolic dominant pattern with diminished diastolic component.

The SDVR is a promising quantitative predictor of LIMA bypass failure.

The status of the coronary arterial bed into which is LIMA implanted and the contractility of the grafted myocardial area are the general qualitative parameters influenced the blood flow profile of LIMA bypass.

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