

Diagnostic accuracy of Doppler ultrasonography for assessment of internal thoracic artery graft patency

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ABSTRACT

Objective: The main purpose of this study was to assess the patency of left internal thoracic artery (LITA) graft by using color Doppler ultrasonography (CDUSG) and furthermore to determine the sensitivity and specificity of CDUSG for patency by using coronary angiography as the reference standard.

Methods: This study is an observational cohort study on diagnostic accuracy that was held between August 2008 and October 2009. CDUSG was performed in 138 consecutive patients who had angina symptom or positive ischemic findings following coronary artery bypass surgery. LITA blood flow velocity at peak-systole (PSV), diastole (PDV) and end-diastole (EDV) was recorded. All patients were also assessed by coronary angiography for LITA graft patency. Statistical analysis was performed by using independent samples t-test, Mann-Whitney-U test, chi-square test and receiver operating curve analyses (ROC).

Results: Seventy-eight of all patients had functional LITA grafts and 59 patients had dysfunctional LITA grafts according to CDUSG-derived parameters, whereas we cannot conclude about one patient's LITA graft functionality. The LITA grafts were visualized angiographically in all cases. Of all 138 patients, 60 patients had dysfunctional LITA grafts after angiographic evaluation. The ROC analyses showed that PDV (AUC=0.899, 95% CI 0.844 to 0.953; p<0.001) and EDV (AUC=0.900; 95% CI 0.847 to 0.953; p<0.001) values were also strongly associated with graft functionality. We found out that CDUSG predicts LITA graft functionality with a sensitivity and specificity of 100% and 98.4% respectively. The accuracy of the CDUSG was calculated as 99.3%.

Conclusion: CDUSG is a reliable non-invasive method for assessment of LITA graft patency. (*Anadolu Kardiyol Derg 2014; 14: 286-91*)

Key words: blood flow velocity, coronary artery bypass grafting, internal thoracic artery, color Doppler ultrasonography, sensitivity and specificity, diagnostic accuracy

Introduction

The left internal thoracic artery (LITA) has become the most preferred conduit for revascularization of left anterior descending coronary artery (LAD) in the present day (1-3). Invasive cardiac catheterization is the only definitive method for assessment of LITA graft patency in the patient with angina or ischemia after coronary artery bypass grafting (CABG). A non-invasive method of assessment would be useful in this group of patients. Color Doppler ultrasonography (CDUSG) has been studied widely for the assessment of LITA graft patency previously (4-9). In these studies, the primary parameter that shows the graft functionality was the ratio of peak flow velocities during diastolic and systolic period. However, each parameter (peak-systolic velocity,

peak, diastolic velocity and end-diastolic velocity) individually have not been studied in detail.

In this observational cohort study, we evaluate LITA to LAD bypass graft patency by CDUSG. The main purpose of the study is to determine the sensitivity and specificity of CDUSG for LITA patencies by conventional coronary angiography as the reference standard and furthermore, to determine the impact of each parameter derived by USG examination individually on assessment of graft patency.

Methods

Study design

The present study was designed as an observational cohort study on diagnostic accuracy of CDUSG.

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Study population and protocol

This study was conducted between August 2008 and October 2009. In this period, 1617 CABG procedures have been performed in our institution. The study group consisted of 138 consecutive patients who had anginal symptoms or positive ischemic test results at follow-up visits after elective CABG with in situ LITA to LAD solely or with additional reversed saphenous vein aortocoronary grafts. Patients had undergone CABG in the same center and all LITA to LAD anastomoses were performed using the same technique. All consecutive patients who were required to be assessed by coronary angiography in this period were enrolled in the study. CDUSG examinations were performed and after that, all patients had undergone coronary angiography for diagnosis.

This study complies with the Declaration of Helsinki and ethical approval was granted by the local institutional review board. Informed consent was obtained from all patients.

Color Doppler ultrasonography technique

CDUSG examinations were performed before angiography within 24 hours. A computerized CDUSG (Logiq 7, General Electric Medical Systems, Milwaukee, WI, USA) equipped with 3-7 MHz linear transducer was used for all studies. All CDUSG examinations were performed by same trained and experienced radiologist. CDUSG was performed through supraclavicular space while the patient was in supine position (4-6). After 15 minutes of resting at supine position, the duplex probe was placed directly on the skin after application of a commercial ultrasonic gel. Probe was positioned to maintain image of left subclavian artery until its vertebral artery origin in longitudinal axis in the first instance. Then probe was turned 90 degrees clockwise and axis of blood flow towards caudal and LITA origin was monitored. Angle correction was applied for the velocity measurements. We measured LITA blood flow velocity (cm/sec) at peak-systole (PSV) and diastole (PDV) and end-diastolic flow velocity (EDV). Then we calculated peak-diastolic to peak-systolic velocity ratio DSVR (PDV/PSV) and the resistance index (RI) by the following formula;

$$RI = (PSV - EDV) / PSV.$$

In an ungrafted LITA, the blood flow shows significant diastolic resistance and henceforth it gives a triphasic flow pattern on CDUSG. There is a high PSV, a low PDV and a very low EDV. This means a low DSVR and a high RI (7-9). When LITA grafted to the LAD, presuming a good surgical anastomosis and normal distal LAD, the flow pattern on Doppler scanning changes from the typical triphasic pattern to a biphasic pattern with increased diastolic flow velocity. The PSV decreases slightly and PDV and EDV increases. This means a high DSVR and a low RI. The flow pattern of an obstructed LITA shows a triphasic pattern similar to that of the ungrafted LITA. Obstruction can occur between the origin of the LITA and the distal coronary bed. Proximally occluded grafts have an absence of flow and distally occluded grafts have a systolic dominant pattern (10-18). A poor LAD target vessel quality, competitive flow from a partially occluded proximal LAD, residual LITA side branches and the contractility and viabil-

ity of the perfused myocardium can affect the Doppler flow values also. All these factors could be associated with diminished diastolic flow of the LITA-LAD bypass (19-21). The DSVR is used because this ratio is independent of the ultrasound beam angle of incidence that effects Doppler calculations (16). In this study, we defined LITA graft as dysfunctional if it had a DSVR lower than 0.6 after calculations (9).

Coronary angiography protocol

Conventional coronary angiography was performed by standard Judkins technique with an imaging system (Artis zee, Siemens Medical Solutions, Erlangen, Germany). The LITA grafts were examined using multiple projections and analyzed whether the LITA graft was functional or not. Observers who blinded to the CDUSG results analyzed the angiograms. The LITA graft was considered being dysfunctional if its occlusion or significant diameter stenosis (>70%) was present, or when slow run-off and persistently small caliber not responding to nitrates were detected. Using the coronary angiography as the standard, we investigated the diagnostic accuracy of CDUSG for LITA graft patency.

Statistical analyses

Continuous variables were tested for normal distribution by Kolmogorov-Smirnov test. Normally distributed continuous variables were expressed as 'mean values±standard deviation (SD)' or median values with the interquartile range if not normally distributed. Categorical variables were expressed as numbers and percentages. Demographic characteristics and CDUSG measures were compared using "independent samples t-test" or "Mann-Whitney U test" for continuous variables and "chi-square test" for categorical variables. Receiver operating characteristic (ROC) curve analysis was used to determine the optimum cut-off levels of the PDV, EDV and RI to assess for functionality. As secondary analysis, relative risks were obtained with the measured values of ROC curve by "chi-square test". A p value <0.05 was considered statistically significant. All statistical analyses were performed using the SPSS statistical software (SPSS for Windows 15.0, Inc., Chicago, IL, USA).

Results

Clinical characteristics

Baseline characteristics according to LITA functionality are listed in Table 1. Study population was predominantly male (M/F: 101/37) with a mean age of 63.0±8.5 years. Time between CABG and catheterization was median of 51 months (range 0-120 months). All patients had sinus rhythm.

Color Doppler ultrasonography and coronary angiography findings

Ultrasonic visualization was obtained successfully in all patients. LITA flow characteristics are shown on Table 2. Seventy-eight patients had functional LITA grafts that showed a characteristic biphasic pattern of blood flow corresponding to systole and

Table 1. Demographic characteristics of patients

Characteristic	All patients (n=138)	Angiographic situation		
		Patent (n=78)	Occluded (n=60)	P value
Age, years	63.0±8.5	61.2±9.0	65.2±7.3	0.006*
Male	101 (37.0%)	60 (76.9%)	41 (68.3%)	0.259†
HT	51 (62.9%)	29 (37.2%)	22 (36.7%)	0.951†
HL	42 (30.4%)	22 (28.2%)	20 (33.3%)	0.516†
DM	48 (34.8%)	25 (32.1%)	23 (38.3%)	0.442†
COPD	24 (17.4%)	11 (14.1%)	13 (21.7%)	0.245†
BMI	23.0±2.1	23.0±1.8	23.1±2.4	0.863*
EF (%)	50.0 (45.0-55.0)	50.0 (45.0-55.0)	50.0 (45.0-55.0)	0.937§
Number of diseases vessels				
1-vessel	30 (21.7%)	17 (21.8%)	13 (21.7%)	0.471†
2-vessel	36 (26.1%)	22 (28.2%)	14 (23.3%)	
3-vessel	72 (52.2%)	39 (50.0%)	33 (55.0%)	
BMI - body mass index; COPD - chronic obstructive pulmonary disease; DM - diabetes mellitus; EF - ejection fraction; HL - hyperlipidemia; HT - hypertension Data are expressed as mean±SD for normally distributed data and median (interquartile range) for skewed data or count (percentage) for categorical variables. *Independent samples t test, †Chi-square test, §Mann-Whitney U test				

diastole with the relative increase in flow during diastole (Fig. 1). Fifty-nine patients had dysfunctional LITA grafts according to our sonographic findings. In 11 patients, we recorded complete loss of the diastolic blood flow with an absent flow or monophasic systolic flow. In 48 patients, we detected decrease of the diastolic flow velocities with systolic dominant broadened pattern.

We cannot conclude about one LITA graft functionality, in which we measured a very high PSV and high PDV and EDV. We could not conclude about its graft patency and after angiography, we found out that LITA graft was dysfunctional. When we assumed this patient's result as false positive, we found out that CDUSG predicts LITA graft functionality with a sensitivity and specificity of 100% and 98.4% respectively. Negative predictive value of CDUSG was 100% and its positive predictive value was 98.7%. The accuracy of the CDUSG was calculated as 99.3%.

Receiver operating characteristic curves for PDV and EDV showed the relation with functionality of LITA graft (Fig. 2). The area under curve for the PDV levels was 0.899 (95% CI 0.844 to 0.953; p<0.001). Using a cut-point of 35.95 cm/sec, the PDV level showed dysfunctionality of LITA graft with a sensitivity of 76% and specificity of 92%. The relative risk for patients with a PDV level lower than 35.95 cm/sec for having a dysfunctional LITA graft was 34.16 (95% CI 11.94 to 97.75 p<0.001, x²=61.78).

The area under curve for the EDV levels was 0.900 (95% CI 0.847 to 0.953; p<0.001). Using a cut-off value of 16.50 cm/sec, the EDV level correlated with the functionality of the LITA graft with a sensitivity of 77% and specificity of 90%. Patients with an EDV level lower than this value had a 30-fold increased risk of having dysfunctional LITA graft (OR 30.00, 95% CI 11.10 to 81.09; p<0.001, x²=60.87).

Table 2. LITA flow characteristics at Doppler scanning

Characteristic	Functional LITA Graft (n=78)	Dysfunctional LITA Graft (n=60)	P value
PSV, cm/sec	54.82±13.45	57.09±11.84	0.302
PDV, cm/sec	43.64±11.78	26.52±8.63	<0.001
EDV, cm/sec	24.53±10.96	9.79±7.21	<0.001
DSVR	0.79±0.05	0.46±0.09	<0.001
RI	0.57±0.11	0.83±0.10	<0.001

DSVR - peak diastolic/peak systolic velocity ratio; EDV - end diastolic velocity; LITA - left internal thoracic artery; PDV - peak-diastolic velocity; PSV - peak-systolic velocity; RI - resistance index

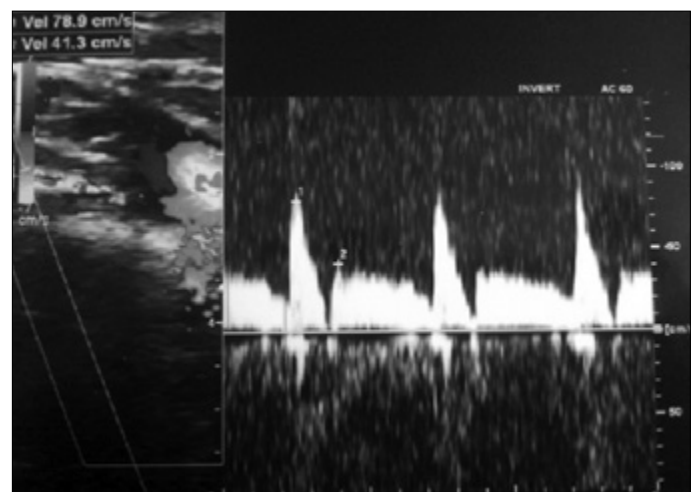


Figure 1. Systolo-diastolic flow pattern of patent LITA graft visualised with color doppler ultrasonography

LITA - left internal thoracic artery

The LITA grafts were visualized angiographically in all cases. Of all patients, 78 patients had functional LITA grafts and 60 patients had non-functional LITA grafts after angiographic evaluation.

Discussion

In our study, we found out that the CDUSG had a sensitivity of 100% and specificity of 98.4% for assessing the LITA graft patency as controlled with the standard method (coronary angiography). In addition to this, the USG-derived parameters -PDV and EDV individually- were strongly associated with LITA graft patency.

The use of LITA graft in myocardial revascularization of LAD has high rate of survival and improves the long-term results of CABG (1-3). However, conventional angiography is the only reliable method to determine the postoperative patency of LITA in spite of its invasivity and well-known disadvantages (22).

CDUSG is widely used to monitor and measure blood flow in peripheral vessels (23, 24). Despite accurate and reliable assessment of native LITA before CABG, we cannot succeed to identify in situ LITA graft accurately after CABG at initial. This is partly because of unfavorable chest wall configuration, coexistent lung diseases and the learning curve experience (25). Hartman

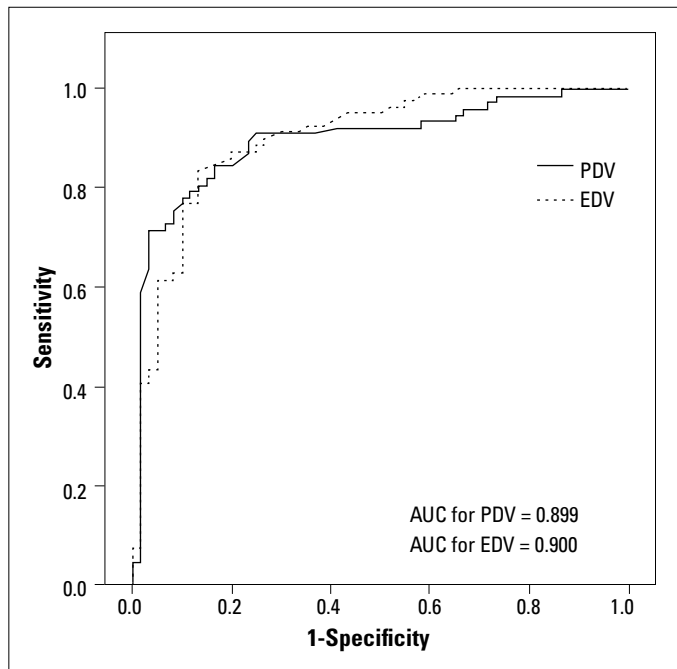


Figure 2. Receiver operating characteristic curves for PDV and EDV
AUC - area under curve; EDV - end diastolic velocity; PDV - peak diastolic velocity

et al. (26) stated that obtaining LITA graft non invasively with the transthoracic approach is difficult because of its narrow lumen and constant pulsatile movement. Therefore they evaluated the LITA graft flow with echo Doppler from the supraclavicular approach because the proximal part of the LITA graft is close to the chest wall and fixed with soft tissue and hence free from pulsatile displacement. Our observations with the supraclavicular approach confirm the reliability of this approach. We tried several imaging studies with CDUSG and finally we developed our technique and started to visualize in situ LITA grafts very accurately. All our LITA CDUSGs were performed by the same radiologist. Canver et al. (25) reported that after trying numerous postoperative imaging studies with CDUSG they reached a rate over 90% while visualizing LITA grafts and suggest that changes in LITA graft flow dynamics may offer the clinician to identify graft failure.

Postoperative color Doppler ultrasonographic LITA studies revealed significant changes from preoperative data. As an adaptation to the coronary circulation, the postoperative LITA flow pattern becomes biphasic instead of triphasic, with an increased peak diastolic velocity instead of systolic pattern (10-18). For the LITA graft anastomosed to the LAD, postoperative data revealed that peak diastolic/systolic velocity ratio of more than 1.0 has been associated with a good angiographic finding indicating increased blood flow into the low resistance distal coronary arterial bed and probably indicating a patent graft. Decreased diastolic flow and low peak diastolic/systolic velocity ratios could be predicted as LITA graft dysfunction (9).

Takagi et al. (9) reported that a diastolic/systolic peak velocity ratio lower than 0.6 predicted severe LITA graft stenosis with a sensitivity and specificity of 100% and 80% respectively after

assessment of LITA graft using color Doppler echocardiography from supraclavicular fossa. Crowley et al. (19) stated that a peak systolic/peak diastolic velocity ratio above 1.00 predict severe stenosis with a sensitivity of 100% and specificity of 85%. In addition, Ichikawa and colleagues (11) stated that these graft flow dynamics were unchanged even after 10 years and this hemodynamic characteristic may be one of the factors related to superior long-term patency. In a review, Jones et al. (20) reported that transthoracic Doppler USG is effective in first-line assessment of LITA graft patency. It shows high specificity, prevents invasive investigations and improves in patients with postoperative angina. Hartman et al. (26) reported that peak diastolic and systolic velocities are the most discriminative factors for string sign LITA grafts and suggest postoperative supraclavicular duplex as a method to assess the patency of LITA to LAD area grafts allows discriminating functional grafts from string sign grafts. We want to mention one of our cases for supporting this suggestion. One patient had anterior ST elevations in electrocardiography immediately after CABG. This patient had in situ LITA to LAD bypass and aorto-right coronary artery bypass with reversed saphenous vein. We performed CDUSG and concluded that this ST elevation was because of LITA graft failure. After verification with coronary angiography, we immediately reoperated the patient and during operation, we saw that there was no flow in LITA graft. After renewing the LAD bypass with reversed saphenous vein anterior ST elevation disappeared and patient had an uneventful postoperative period. This case alone may reveal that Doppler assessment of internal mammary artery grafts is easily useful.

When we analyzed our results, we found that the location site of the obstruction resulted in two different patterns of the Doppler spectrum. In case of proximal occlusion, LITA graft functions as a blind-ended tube associated with monophasic systolic flow and the loss of diastolic component proximal to the place of occlusion. In case of significant distal stenosis or occlusion, the Doppler spectrum is characterized by a decrease in the diastolic flow component with the broadening of the Doppler spectrum, but not the complete loss of diastolic flow. These qualitative observations showed that an index incorporating both diastolic and systolic flow components could better reflect the impact of lesion on hemodynamics rather than sole analysis of the diastolic component. Our findings are consistent with those observations in the literature (9-23) and when we compare our Doppler findings with our angiographic findings, we found out that almost all our Doppler evaluations are verified by angiographic findings. Low resistance biphasic flow with dominant diastolic component is typical for patent LITA grafts. Suspicion of the graft failure should be raised when there is an absent flow or a systolic dominant pattern with diminished diastolic component.

Furthermore, the variables PDV and EDV separately have been found to be closely dependent with functionality of LITA graft by ROC analysis in our study (RR 34.16 and 30.00 respectively). However, the reliability of these variables as a new index may be reevaluated by further studies.

Study limitations

Major limitation of our study was the patient population. Study group consisted of patients who referred to clinical-driven evaluation of graft patency at angiography. We did not evaluate all the patients who had undergone CABG previously. All consecutive patients who were required to be assessed by coronary angiography (as indicated for presenting symptoms and after positive ischemic test results) were enrolled in the study. In our study, assessment of the LITA graft functional status was performed at rest. It is likely that a stress study using administration of vasodilators (adenosine, dipyridamole) with evaluation of flow reserve in the LITA graft could have increased the sensitivity and accuracy of the color Doppler USG examination (27). In addition, the status of the coronary arterial bed into which is LITA implanted and the contractility of the grafted myocardial area are the general qualitative parameters influenced the blood flow profile of LITA bypass (28). Seki et al. (29) indicated that LITA grafts have flow adaptability and respond to the flow demand of the recipient coronary artery and concluded that the internal thoracic graft was smaller in patients with well-preserved flow of the native coronary artery and that LITA string sign grafts developed mainly as an outcome of the absence of its physiological demand. Although our data showed that the parameters-PDV and EDV individually-are strongly associated with LITA graft failure, these parameters should be further studied with other studies and different patient populations, considering that these results of PDV and EDV are dependent on the data that was proven previously.

Conclusion

Despite these limitations, supraclavicular CDUSG assessment of in situ LITA graft has the clear advantage of being less invasive and having fewer complications than cardiac catheterization studies. Because the technique is completely noninvasive, it is a realistic method for assessing patency of the graft over time. It can also be suggested that conventional angiography may be reserved for patients whom LITA flow patterns show abnormal flow patterns. With advancements in Doppler technology efforts to better identify LITA and other grafts and their flow patterns may secure a new useful non-invasive surveillance method to assess patients who underwent CABG in immediate future. This technique may also represent a valuable method for physiologic or pharmacologic investigations.

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