Ultrasound evaluation of vascular graft-related parameters before and after in situ left internal mammary artery bypass

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Abstract

Background: Ultrasound is frequently used to assess the function of heart and blood vessels. Here, we used ultrasound to evaluate the changes in vascular-graft-related parameters in patients with coronary heart disease before and after in situ left internal mammary artery (IMA) graft and assessed factors affecting blood flow in the graft. Methods: We collected data on 60 patients who underwent coronary artery bypass grafting (CABG) under the same surgeon. All ultrasonic parameters of IMA before and after CABG were measured using Philips EPIQ7 Ultrasound Machine. We then compared changes in all the parameters and assessed factors affecting IMA blood flow. Results: Postoperative IMA had wider luminal diameter than preoperative IMA, higher peak systolic and peak diastolic velocities, reduced resistance index, and significantly greater diastolic velocity-time integral and its fraction. The IMA-left subclavian artery angle was negatively correlated with intraoperative flow of vascular graft, and the blood flow of the graft was significantly higher 1 week postoperatively than it had been during the operation. Conclusions: In situ IMA bypass in CABG patients increased vascular graft luminal diameter and flow, and the angle between IMA and subclavian artery affected the postoperative flow of the vascular graft.

Background

Cases of coronary heart disease have been increasing in recent years and appearing in younger patients [1]. Coronary artery revascularization can improve long-term patient prognosis and quality of life. Ever since the American College of Cardiology Foundation and American Heart Association (ACCF/AHA) revised the Guidelines for Coronary Artery Bypass Grafting (GABG) in 2011[2], CABG procedures have been significantly more numerous and *in situ* left internal mammary artery (IMA)-anterior descending branch bypass grafting has become the first choice for clinicians, with the treatment rate increasing from 31% in 1988 to 91% in 2008 [3], leading to better immediate and long-term postoperative outcomes (i.e., lower rates of mortality, myocardial infarction, and reoperation) than venous grafts, and 90–97% 5-year patency rates [3,4]. Although coronary angiography is the gold standard for evaluating the patency of vascular grafts, ultrasound, a non-invasive and reproducible method of examination, has been adopted in clinical practice. It would be of great value for evaluating the preoperative related parameters of IMA and the postoperative graft patency to effectively assess the success rate of surgery and the prognosis of the patients. In this study, we mainly used ultrasound to evaluate the changes in related parameters of IMA before and after the *in situ* CABG in IMA and the factors affecting the postoperative flow of the vascular grafts.

Materials and methods

Patients

Sixty patients received CABG from the same surgeon from July 2016 to April 2018 (43 males and 17 females, aged 44–76 years, mean age of 61 ± 6 years) were included in this study. All patients suffered from myocardial ischemia because of one or more stenoses of coronary arteries. There were 45 patients with lesions in three or more main branches of the coronary artery, 7 patients with lesions in two branches of the coronary artery, and 8 patients with lesion in only one main branch of the coronary artery. They underwent *in situ* left IMA bypass to the left anterior descending coronary artery (n = 6 only used left IMA-anterior descending branch as vascular grafts; n = 54 also used saphenous venous grafts). Their general data were collected. Luminal diameters and blood flow of the bilateral IMA of all patients were assessed preoperatively. The ultrasound parameters related to the left IMA were reexamined approximately 1 week after the surgery to evaluate the blood flow and analyze the factors affecting the flow of vascular grafts. The protocol of this study was approved by the ethics committee. All patients signed written informed consent forms before participating in this study.

Exclusion criteria of this study included congenital heart diseases or other structural heart diseases, any significant reduction of left ventricular function (<30%) or recent heart failure, lesions in proximal subclavian artery, vascular graft other than the left IMA to anterior descending branch, and intraoperative rupture in the proximal region of left IMA.

Methods

Preoperative examination of bilateral IMAs

Each patient was examined in the supine position with a Philips EPIQ7 Ultrasound Machine (United States) with L12-3 frequency of 3–12 MHz, connected to electrocardiography. To examine the left IMA, the probe was placed on the fourth intercostal space on the left side of the sternum and moved to the left to search for IMA. Luminal diameter was measured in the two-dimensional image. The angle between the sound beam and the blood flow was adjusted to <60°. Spectral Doppler ultrasound was used to measure the peak systolic velocity (PSV), peak diastolic velocity (PDV), systolic velocity–time integral (sVTI, integrating instantaneous speed with time to obtain distance of systolic blood flow), and diastolic velocity–time integral (dVTI, integrating instantaneous speed with time to obtain distance of diastolic blood flow) and to calculate resistance index (RI=PSV/PDV) and diastolic velocity–time integral fraction [dVTIF = dVTI/(dVTI + sVTI)]. The mean values of three cardiac cycles were then used for analysis. Examination of the right IMA was performed using the same method as in the left IMA.

Assessment of IMA initial segment after the operation

Each patient was examined in the supine position with a Philips EPIQ7 Ultrasound Machine (United States) with L12-3 frequency of 3–12 MHz, connected to electrocardiography. The probe was placed on the left neck region, along the axis of the vertebral artery to visualize the beginning of the vertebral artery in the supraclavicular fossa. The probe was then rotated 90° to the opposite side of the vertebral artery (inferior wall of the subclavian artery) to detect the opening of the left IMA and to measure the angle between the left IMA and the subclavian artery. The luminal diameter of the IMA was measured at a distance of 0.5–1.0 cm from the opening. Spectral Doppler ultrasound was used to find the spectrum of the initial segment of the IMA after the operation, to measure PSV, PDV, sVTI, and dVTI, and to calculate RI, dVTIF, and PDV/PSV ratio (D/S). The mean values of three cardiac cycles were then used for analysis. The flow of IMA was calculated using to the luminal diameter.

All operations were performed by the same deputy chief physician.

Statistical analysis

SPSS17.0 software (SPSS IBM Inc., Chicago, IL, US) was used for statistical analysis. Measurement data are here presented as mean ± standard deviation (x ± s). Normally distributed measurement data were compared using paired t-test. Non-normally distributed measurement data were compared using signed rank sum test of paired data, and comparison of the count data was performed using chi-square test. Correlation analysis was performed using logistic regression analysis. $P< 0.05$ was considered statistically significant.

Results

General data-related indicators are shown in Table 1. These indicators were found to have no significant effect on the flow of vascular grafts.

In this study, all patients clearly showed the IMA lumen and flow spectrum (100%) at the fourth intercostal space next to the sternum. The preoperative IMA flow spectrum showed systolic dominance, and the RI was high (Fig. 1a). Luminal diameter of postoperative IMA was wider than that of preoperative IMA. The postoperative PSV and PDV of IMA were significantly increased. The postoperative RI of IMA was reduced. The postoperative dVIT and dVITF of IMA were significantly increased (Table 2). Indicators of left ventricular function (such as EDV and SV) and blood flow between patients on- and off-pump during CABG have no significant difference ($P > 0.05$, Table 3).

Logistic regression analysis showed that the angle of the IMA and left subclavian artery was negatively correlated with the intraoperative vascular graft flow (= -1.88 x Angle + 344.13, $P = 0.00$, $R^2 = 0.23$, Fig. 2). The vascular graft flow in at 1 week after surgery was significantly higher than the intraoperative vascular graft flow ($P = 0.00$, Table 4). All patients showed clinical improvement after surgery, but there was no significant difference in left ventricular function indicators.

Discussion

The bilateral IMAs are relatively superficial and in relatively fixed positions. Because of the relatively high peripheral vascular resistance before the operation, the blood flow of IMA demonstrated a triphasic flow spectrum with high systolic velocity and low or no diastolic velocity. One of the patients included in the postoperative follow-up had intraoperative rupture of the initial segment of IMA, but the remaining patients were able to undergo the measurements of luminal diameter of the initial segment of IMA and flow spectrum. Previous studies have shown that the success rate of exploration of initial and thoracic segments (the second intercostal space) of IMA after CABG is >99.5% [5], and the changes in the hemodynamics of the vascular grafts may indicate abnormal function of these vascular grafts, with sensitivity and specificity of 100% and 98.4%, respectively [6]. The spectrum of the left IMA changes from a triphasic form to biphasic form to supply the coronary vascular bed with low resistance after surgery, with a significant increase in diastolic velocity and significant decrease in systolic velocity and RI [7]. In addition, the diastolic component of flow spectrum increases gradually from the initial segment of IMA to vascular graft anastomosis[8, 9]. In this study, the postoperative PSV and PDV increased significantly ($P < 0.05$). The differences between the pre and postoperative PSV and PDV may be related to the intraoperative treatment of IMA and postoperative assessment of the location of IMA. In addition, the postoperative dVTI and dVTIF were significantly increased. These results were consistent with the findings of previous studies. Biceroglu et al. [10]conducted a three-year follow-up study of 38 patients who underwent CAGB and found that approximately 18% of patients had collateral vessels in the left IMA, with vascular diameters similar to the luminal diameter of IMA and competitive flow between the collateral vessel and vascular graft [10]. In addition, the ossification of IMA alone affects the flow of vascular grafts [11]. In this study, all patients had pedicled left IMA, ligation of all collateral vessels, and *in situ* bypass of left IMA to left anterior descending coronary artery. The surgical procedures were performed by the same surgeon. Because of the free IMA and apparent parasternal gas interference, we selected the supraclavicular region to evaluate the initial segment of IMA postoperatively. An abnormal flow spectrum strongly suggests abnormal vascular grafts and warrants consideration of a timely clinical intervention.

In this study, indicators of left ventricular function (such as EDV and SV) showed no statistically significant differences. A short period of myocardial stunning, which is reversible, was found after ischemic myocardial reperfusion. It takes a long time from reperfusion to full recovery of myocardial function after CABG. Lin et al.19] reported the critical point to be 6 months postoperatively. The postoperative PDV, D/S, and dVTIF showed no statistically significant effect on the flow of vascular grafts. Takagi et al.[12] showed the postoperative D/S of initial segment of IMA to be >0.6 and the dVTIF >0.5, indicating good functions and flow of vascular grafts. Other studies have shown that severe stenosis in anastomosis between left IMA and left anterior descending branch occurs when the blood flow S/D >1, with sensitivity and specificity of 100% and 85%, respectively [13]. By comparing the results of coronary artery angiography and ultrasound to evaluate the function of vascular graft, researchers have found that when the postoperative PDV is <35.95 cm s^{-1}, the probability of functional abnormality of the vascular graft increases by 34.19-fold[6]. The related parameters in this study had no significant effect on the flow of vascular graft, suggesting that although some patients had multiple coronary vascular lesions and different degrees of stenosis at the distal end of the anterior descending coronary artery, patients with a >50% degree of stenosis had detectable changes in the ultrasonic spectrum. In addition, their arteries had a certain flow reserve capacity, and their vascular flow and flow spectrum of vascular grafts would change after exercise and pressure load [14, 15]. Therefore, patients' medications and exercise states may also have an impact on the study results. This matter requires further investigation.

Wu et al. [16] conducted a flow distribution study and showed that when the pressure in a Y-shaped connection pipe remained unchanged, the flow distribution of gas-solid biphasic fluid was related to the angle between the movable branch and main pipe and to the flow rate of the main pipe. In addition, the changes in angle had a pronounced impact on the flow distribution. However, these results have not been confirmed in medical research. In this study, clear differences in angle between the IMA and the subclavian artery (101–156deg) were found among individuals. Logistic regression analysis revealed that the angle between the IMA and the subclavian artery was negatively correlated with intraoperative flow rate, suggesting that the angle may be an independent factor affecting the flow of vascular grafts. This suggests that the angle between the IMA and the subclavian artery after*in situ* bypass in the left breast may be an independent factor to affect the flow after CABG.

In this study, the instantaneous volume blood flow and pulsatility index of the vascular graft were intraoperatively measured using a coronary blood flow instrument. The flow of the vascular graft at 1 week postoperatively was calculated according to the luminal diameter of the initial segment of vascular graft measured by ultrasound. Through the paired t-test, we found the flow to be significantly increased at 1 week postoperatively, and the luminal diameter of the vascular graft was widened postoperatively ($P = 0.002$). Tagusari et al.[17] found that the luminal diameter of vascular graft was widened by 1.43-fold, and the flow of vascular graft was increased by 4.18-fold two weeks after CABG. In addition, the short-term and low-term postoperative blood flow had no significant difference[14]. Nasu et al. [18]compared the results of coronary angiography and Doppler ultrasound velocimetry and showed that mild to moderate stenosis in the proximal coronary arteries of CABG patients was caused by the presence of competitive flow. The flow of vascular grafts was lower than the blood flow of patients with severe stenosis. Therefore, if abnormal flow of the vascular graft is observed in patients during a postoperative follow-up and competitive flow can be ruled out, functional abnormality of the vascular graft should be considered and a timely clinical treatment should be applied.

Limitations

In this study, the number of lesional blood vessels before the operation and the number of intraoperative vascular grafts differed among the patients. In this way, the evaluation of blood flow in the IMA may have different degrees of impact. In addition, the patency of vascular grafts was not confirmed by angiography.

Conclusions

The luminal diameter and flow of vascular grafts of the CABG patients who underwent *in situ* left IMA bypass increased after the operation, and the flow of vascular grafts at 1 week postoperatively was significantly greater than the intraoperative level. The angle between IMA-subclavian artery affected the postoperative flow of vascular graft. Therefore, related parameters of left proximal IMA in the postoperative follow-up could be used to assess the patency of vascular grafts in the patients.

Abbreviations

IMA: left internal mammary artery; CABG: coronary artery bypass grafting; ACCF/AHA: American College of Cardiology Foundation/American Heart Association; PSV: peak systolic velocity; PDV: peak diastolic velocity; sVTI: systolic velocity–time integral; dVTI: diastolic velocity–time integral; RI: resistance index; dVTIF: diastolic velocity–time integral fraction; D/S: peak systolic velocity/peak diastolic velocity.

Author contributions

LIHONG WANG (first author), HONGYUE MAO (co-first author) and MINGHUI SUN (co-first author) acquisition of data, analysis and interpretation of data, drafting/revising the manuscript, control and guarantee that all aspects of the work was investigated and resolved. LIHONG WANG approved the final manuscript. LIHONG WANG , HONGYUE MAO and MINGHUI SUN approved the final manuscript.

LEI ZHENG acquisition of data, and interpretation of data, drafting/revising the manuscript. LEI ZHENG approved the final manuscript.

PENG ZHAO acquisition of data, and interpretation of data, drafting/revising the manuscript. PENG ZHAO approved the final manuscript.

HONGYAN LI (corresponding author) acquisition of data, analysis and interpretation of data, drafting/revising the manuscript, control and guarantee that all aspects of the work was investigated and resolved. HONGYAN LI approved the final manuscript.

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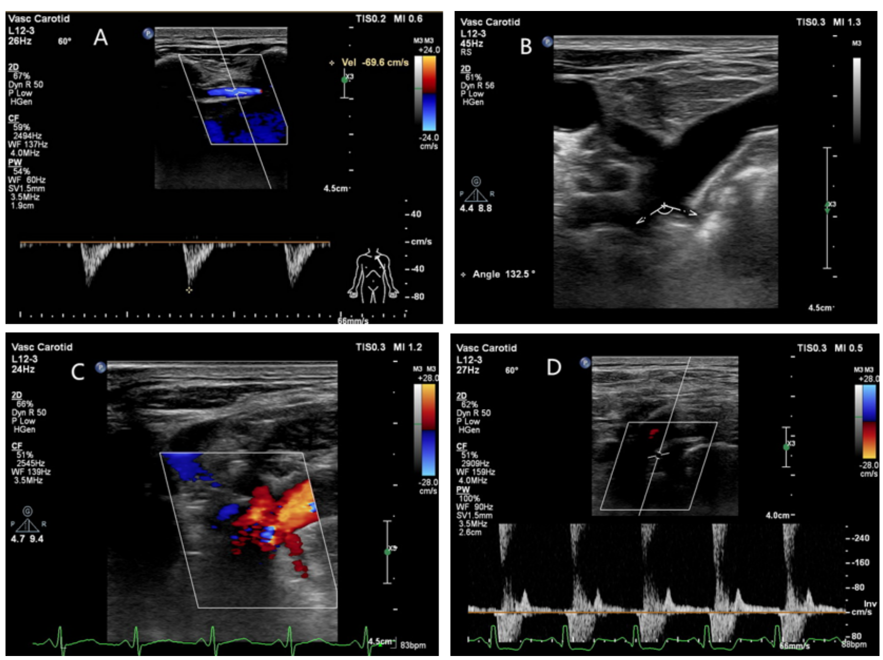
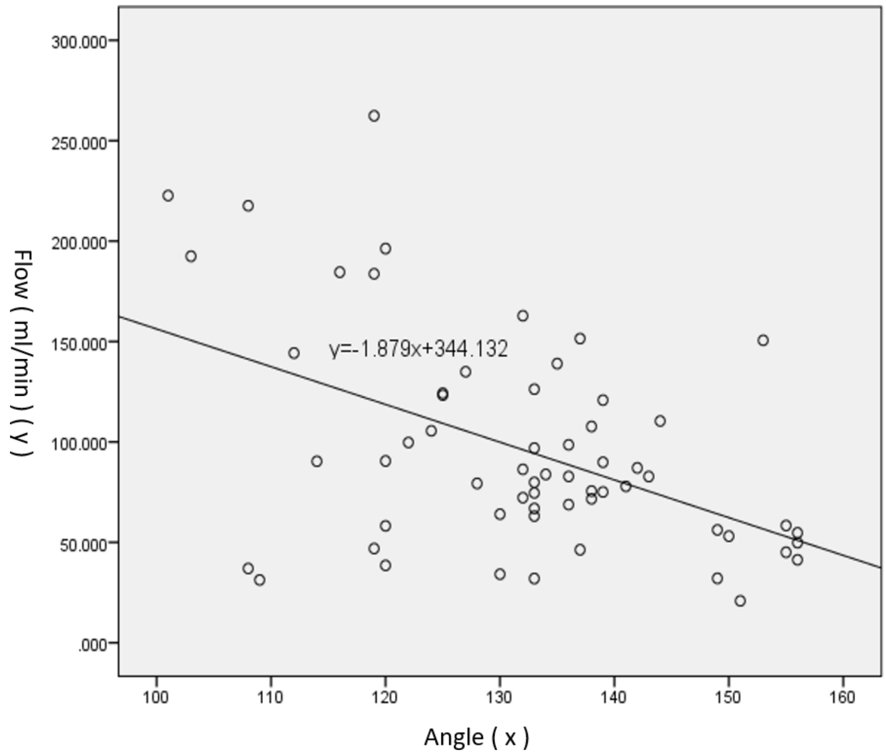
Figure Legends:

Figure 1: A. Spectrum of the preoperative IMA demonstrated a systolic dominance and high RI. B. Measurement of the angle between the initial segment of IMA and the subclavian artery. C. Color-flow Doppler image of IMA. D. Postoperative flow spectrum of IMA.

Figure 2. Regression analysis of the correlation between intraoperative vascular flow and angle between the internal mammary artery (IMA) and the subclavian artery. Flow: intraoperative flow in the vascular graft; Angle: angle between the IMA and the subclavian artery.





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