J Anesth (2009) 23:1–5
DOI 10.1007/s00540-008-0684-5

Journal of
Anesthesia

Original articles

Cuff occlusion on the left upper arm increases flow of the left internal mammary artery and bypass flow to the left anterior descending artery

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Abstract

Purpose. Changes in vascular resistance in the left forearm may affect the flow of left internal mammary artery (LIMA)-to left anterior descending artery (LADA) bypass, because the LIMA is a major branch of the subclavian artery. We studied the effects of occlusion of the left upper arm on blood flow of LIMA-to-LADA bypass in patients undergoing coronary artery bypass grafting (CABG).

Methods. In ten patients, the blood volume shed from LIMA with the distal end open (LIMA free flow) was stored for 1 min before and during cuff inflation in CABG surgery. LIMA-LADA bypass flow was measured with ultrasonic flowmetry before and after cuff inflation on the left upper arm in an other ten patients. Mean arterial blood pressure (MAP), heart rate (HR), and electrocardiograms (ECGs) were monitored throughout the studies.

Results. LIMA free flow ($ml \cdot min^{-1}$) increased from 50.3 ± 7.1 to 60.9 ± 8.4 ($P < 0.01$) at the end of 1-min cuff inflation. LIMA-LADA bypass flow ($ml \cdot min^{-1}$) increased from 31.4 ± 3.7 to 39.7 ± 4.0 ($P < 0.05$) at 1 min after cuff inflation. MAP, HR, and ST segments on ECGs did not show any significant changes related to measurement times.

Conclusion. LIMA-LADA bypass flow increased after cuff inflation on the left upper arm and returned to the baseline values after cuff deflation. Anesthesiologists should be aware of this relationship between local vascular resistance and bypass flow for the evaluation of LIMA-LADA anastomosis.

Key words LIMA flow · LIMA-LADA bypass flow · CABG

Introduction

For more than two decades, it has been recommended that the left internal mammary artery (LIMA) be used for coronary artery bypass grafting (CABG) to the left anterior descending artery (LADA). The adequacy of blood flow through the LIMA-LADA anastomosis is usually measured with a flow probe that determines quantitatively or qualitatively whether the flow is adequate after coronary anastomosis. However, only the absolute value of LIMA-LADA bypass flow has been frequently evaluated, with little mention of the influence of vascular resistance in the upper arm and aortic pressure. The blood flow in LIMA, which is a major branch of the subclavian artery, could be influenced by changes of vascular resistance in the upper arm, because the distribution of blood flow is dependent on the disequilibrium of vascular resistance at the branching point. In fact, the subclavian steal phenomenon has been reported recently in the clinical setting [1–8]. Our hypothesis is that changes in vascular resistance in the left upper arm are one of the factors contributing to LIMA-LADA bypass flow in patients with CABG. In the present study, we hypothesized that abrupt increases in vascular resistance in the left upper arm would increase LIMA-LADA bypass flow in patients undergoing CABG surgery under anesthesia.

Patients and methods

The study consisted of two parts (outlined below). The subjects were adult patients scheduled for cardiac surgery on cardiopulmonary bypass (CPB). To omit patients with subclavian artery stenosis, patients with a systolic pressure difference greater than 20 mmHg between the left and right arms were excluded [3,5]. The protocol was approved by our University Ethics Committee and informed consent was obtained from all the participants before starting the study.

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Received: February 29, 2008 / Accepted: August 11, 2008

Part 1: measurements of LIMA flow with the distal end open before anastomosis

Ten patients (age, 65.0 ± 2.7 years) undergoing CABG, including LIMA-LADA bypass, were enrolled in the part 1 study. In both the part 1 and part 2 studies, all patients received flunitrazepam (0.5 mg orally) 1 h prior to anesthesia. Anesthesia was induced with intravenous midazolam (10 mg), fentanyl (200 μg), and 0.1 $mg \cdot kg^{-1}$ vecuronium followed by tracheal intubation. Propofol (3–6 $mg \cdot kg^{-1} \cdot h^{-1}$) was infused during the period of CPB. After the induction of anesthesia, the radial arteries were cannulated on both sides for blood pressure monitoring. To maintain mean arterial pressure (MAP) above 50 mmHg, we administered a bolus injection of phenylephrine and a continuous infusion of dopamine at the rate of 3–5 $\mu g \cdot kg^{-1} \cdot min^{-1}$. A continuous infusion of nitroglycerin and/or diltiazem at the rate 0.3–0.5 $\mu g \cdot kg^{-1} \cdot min^{-1}$ was administered as required. Before the induction of CPB, LIMA free flow was measured by storing the blood shed from the open end of the LIMA in the operation field for 1 min. A blood pressure cuff applied to the left upper arm was inflated for 1 min to more than 200 mmHg and then deflated. LIMA free flow and MAP were determined at the following two points: immediately before and 1 min after cuff inflation. The rates of administration of vasoactive agents and vasodilators were not changed during the measurement of blood flow.

Part 2: measurements of LIMA-LADA bypass flow

Another ten patients (age, 67.8 ± 3.2 years) undergoing CABG, including LIMA-LADA bypass, were enrolled in the part 2 study. Anesthesia was induced and maintained as in the part 1 study. After the termination of CPB, inhalation of 1% sevoflurane combined with propofol infusion (1–3 $mg \cdot kg^{-1} \cdot h^{-1}$) was continued during the measurements. A total amount of about 15–20 $\mu g \cdot kg^{-1}$ fentanyl was given during anesthesia. When MAP reached more than 60 mmHg and was kept stable after the termination of CPB, LIMA-LADA bypass flow was measured, using transit-time ultrasonic flowmetry (HT207, H3MB; Transonic Systems, Ithaca, NY, USA). All the parameters were recorded on a PC by using digital recording software (LaBDAQ; Matsuyama Advance, Ehime, Japan). Mean flow was calculated for three beats. The blood pressure cuff applied on the left upper arm was inflated to more than 200 mmHg for 1 min and then deflated. Bypass flow, HR, MAP, and ST deviation on ECGs (lead II, V5) were determined at the following four points: immediately before cuff inflation, 1 min after cuff inflation, immediately after cuff deflation, and 1 min after cuff deflation.

Statistics

All parametric data values are presented as means and SE. In the part 1 study, statistically significant differences between groups were analyzed using the paired *t*-test. In the part 2 study statistically significant differences between groups were analyzed using repeated-measures analysis of variance (ANOVA), and Bonferroni's multiple comparison. Significance was defined as a P value of <0.05. The statistics program used for the analysis was SPSS 11.5 J for Windows (SPSS Japan, Tokyo, Japan).

Results

Part 1: LIMA free flow study

LIMA free flow increased after cuff inflation, from 50.3 ± 7.1 to 60.9 ± 8.4 ($ml \cdot min^{-1}$; $P < 0.01$). LIMA free flow increased after cuff inflation for all patients. MAP showed no significant changes related to measurement times (Fig. 1).

Part 2: LIMA-LADA bypass flow

LIMA-LADA bypass flow increased after cuff inflation, from 31.4 ± 3.7 to 39.7 ± 4.0 ($ml \cdot min^{-1}$; $P < 0.05$) and returned to 32.3 ± 3.4 ($ml \cdot min^{-1}$) at cuff deflation (Fig. 2). LIMA-LADA bypass flow increased after cuff inflation for all patients, and the LIMA-LADA bypass flow did not fall below the control value following the release of cuff inflation. None of the values for MAP, HR, and ST deviation of ECGs showed any significant changes related to measurement times.

Discussion

In the present study, we investigated whether external occlusion of the left upper arm increased the blood flow of LIMA-LADA bypass in CABG patients. We note that we observed no deterioration of blood flow with LIMA-LADA bypass below the control value when the upper arm cuff was suddenly deflated.

Cardiac surgeons generally evaluate the quality of coronary anastomosis by measuring LIMA-LADA bypass flow. However, coronary bypass flow is influenced by many factors, including aortic pressure, the vascular resistance of the LIMA, and the quality of the anastomosis. Upper arm vascular resistance also appears to be a factor influencing LIMA bypass flow after CPB. We found that the cuff inflation on the forearm obviously increased LIMA-LADA bypass flow, although MAP did not change during this maneuver. The following mechanism was speculated to have been responsible

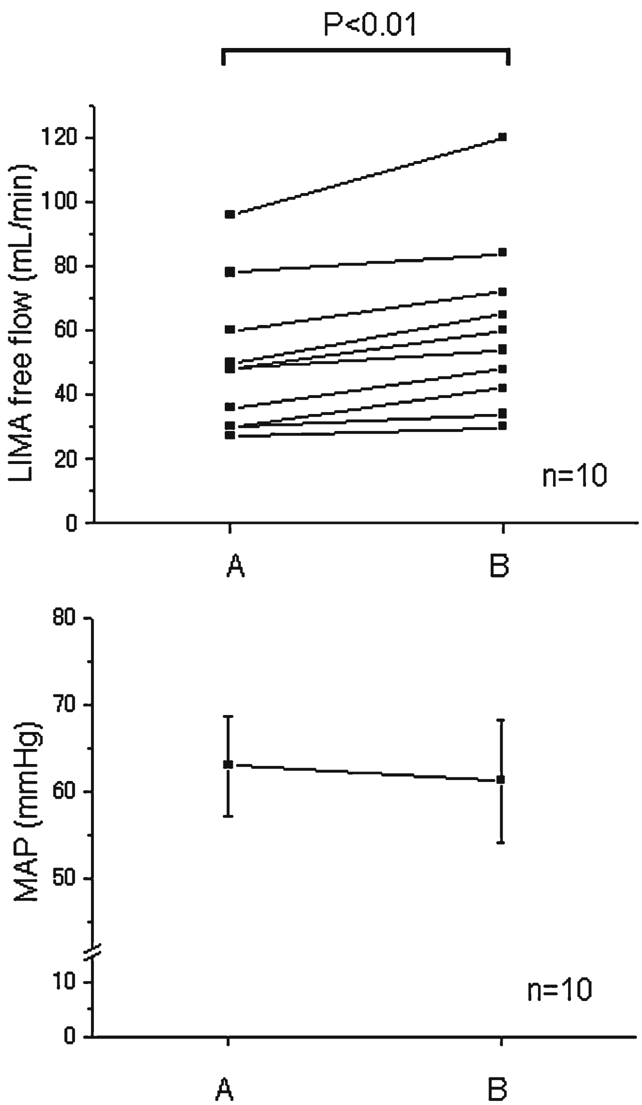

Fig. 1. Sequential changes in left internal mammary artery (*LIMA*) free flow (blood flow shed from the LIMA with the distal end open) and mean arterial blood pressure (*MAP*) on the right arm. *A*, *B*, Immediately before and 1 min after cuff inflation, respectively. Values are expressed as means ± SE

for increasing LIMA-LADA bypass flow during cuff occlusion.

According to Bernoulli's equation, in a single streamline of flow, the sum of kinetic energy, including static energy and potential energy of the bloodstream, remains constant at each branching point along the path of flow. When the blood flow of the brachial artery was interrupted by inflation of the upper arm cuff, the intravascular pressure of the subclavian artery increased and approached aortic pressure; therefore, the blood flow of LIMA would have increased according to the rise of intravascular pressure at the branching point of LIMA during occlusion of the brachial artery.

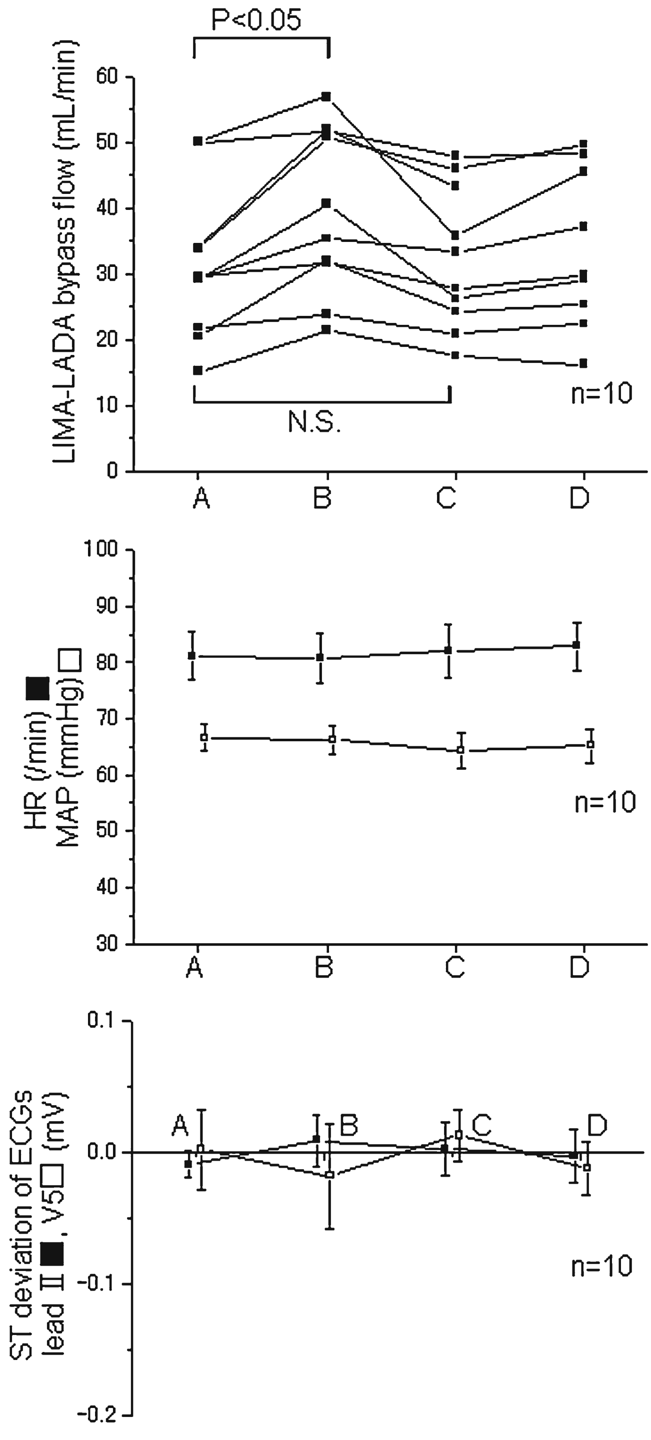

Fig. 2. Sequential changes in left internal mammary artery (*LIMA*)-left anterior descending artery (*LADA*) bypass flow, systemic hemodynamics, and ST deviation of electrocardiograms. *A*, *B*, Immediately before and 1 min after cuff inflation, respectively; *C*, *D*, Immediately and 1 min after cuff deflation, respectively. Values are expressed as means ± SE. *HR*, Heart rate; *N.S.*, not significant

Diastolic arterial pressure is known as the most important factor that modulates the coronary flow, because the blood is mainly supplied into the endocardium during the diastolic phase. However, the flow pattern of LIMA-LADA bypass is considered to resemble that of the epicardial artery, in which the blood flow would be supplied during one cardiac cycle. It is clinically important for maintaining MAP to supply the LIMA-LADA bypass flow into the myocardium. Therefore, in this study, we used the MAP value, rather than the diastolic arterial pressure, as a parameter of the driving pressure of LIMA-LADA bypass flow.

The increase in intravascular pressure of the subclavian artery during cuff occlusion is dependent on the degree of peripheral vasodilatation in the upper arm before cuff occlusion is started on the upper arm. Many cardiac patients need vasoactive agents such as noradrenalin following the termination of CPB because of excessive vasodilatation, mainly caused by the continuous infusion of coronary vasodilators and passive rewarming with CPB. Excessive vasodilatation is known to cause gradients between the intravascular pressures of the aorta and radial artery, which could reduce LIMA blood flow [9]. Repeated external occlusion of the upper arm may counteract the reduction of LIMA blood flow in this situation.

On the other hand, LIMA-LADA bypass flow may decrease when the cuff occlusion on the upper arm is released. Whether the flow of LIMA-LADA bypass decreases below the control level depends on the degree of dilatation of the peripheral vasculature in the upper arm. In the present study, 1 min of upper arm occlusion was not considered long enough to decrease the blood flow of the LIMA branch below the baseline value. As a longer duration of upper arm occlusion could induce maximum dilatation of the peripheral vasculature, it should be investigated whether longer occlusion changes LIMA blood flow following the release of external occlusion on the upper arm.

An arterial graft is considered to be superior to a venous graft for the long-term patency of a bypass graft [10–12]; however, an arterial graft as a coronary bypass graft tends to reduce bypass flow for a few days after coronary surgery, because of the high wall tension of the rich smooth muscle of arterial vessels and the active contraction of arterial vessels, known as vascular spasm, compared to the low vascular wall tension of a venous graft [13–16]. Although many cardiac assistance systems, such as intraaortic balloon pumping and an artificial heart, are obviously effective for patients with a failing or ischemic heart, these devices are all invasive and possibly cause iatrogenic complications such as arterial emboli or dissection of the aorta. Repeated external occlusion of the brachial artery could increase LIMA-LADA bypass flow without any invasive procedure. We found that although the increase of coronary flow by external occlusion of the brachial artery was only 26.4% of the baseline coronary flow, a 26.4% of increase in myocardial flow was considered effective and helpful for survival of the regional ischemic myocardium, because myocardial function failed with only 20%–30% of myocardial blood flow.

In the present study, we excluded patients with subclavian steal syndrome, especially in those patients with stenosis or occlusion of the left subclavian artery [1,2]. The reduction of LIMA flow was augmented by shifting the blood flow to the vertebral artery in restrictive flow. Several reports have been published suggesting that subclavian artery stenosis or occlusion could cause angina after CABG in patients with coronary subclavian steal syndrome [3–8]. There was no stenosis or occlusion of the subclavian artery in our patients, and LIMA blood flow and LIMA-LADA bypass flow did not decrease below the preocclusion value following the release of brachial artery occlusion. It is uncertain whether coronary subclavian steal syndrome could be induced by releasing brachial occlusion in patients with stenosis of the subclavian artery.

Our study has some limitations. First, we established a theoretical event for a human, but we did not have any relevant clinical data as evidence for cuff occlusion on the left upper arm for cardiac ischemic patients after CABG. Further study is necessary to clarify the clinical importance and relevance of cuff occlusion in patients with ischemic heart disease. Second, an examination of the effects of the cuff occlusion period was not performed. The response of LIMA blood flow after a longer period of left upper arm occlusion might be quite counterproductive. In conclusion, LIMA-LADA bypass flow significantly increased during cuff inflation on the upper arm in CABG patients without any deterioration of coronary bypass flow after cuff deflation. Anesthesiologists may need to know about the relationship between peripheral vascular resistance in the forearm and bypass flow for the evaluation of LIMA-LADA anastomosis.

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